Lecture 13

EM: Grounded Sources

GEOL 4397: Electromagnetic Methods for Exploration
GEOL 6398: Special Problems

Jiajia Sun, Ph.D.

Oct. 25th, 2018

UNIVERSITY of HOUSTON
YOU ARE THE PRIDE
EARTH AND ATMOSPHERIC SCIENCES

New schedule

10	10/23 Tues	Lab: Frequency domain EM	Report due on 10/30 @ 4 PM
	10/25 Thur	Lecture: EM_grounded sources	
11	10/30 Tues	Lecture: EM_grounded sources	
	11/01 Thur	Lab: EM_grounded sources	Report due on 11/8 @ 4 PM
12	11/06 Tues	Lecture: Recap & Review	
	11/08 Thur	Exam	
13	11/13 Tues	Lecture: EM_natural sources	
	11/15 Thur	Lecture: EM_natural sources	
14	11/20 Tues	Lab: EM_natural sources	Report due on 11/27 @ 4 PM
	11/22 Thur	No class due to Thanksgiving	
15	11/27 Tues	Final presentation	
	11/29 Thur	Final presentation	

Agenda

- Recap: DC
- Recap: Inductive source EM
- Grounded source EM: motivation
- Grounded source EM: halfspace
- Grounded source EM: with a conductive target
- Grounded source EM: with a resistive target
- Summary

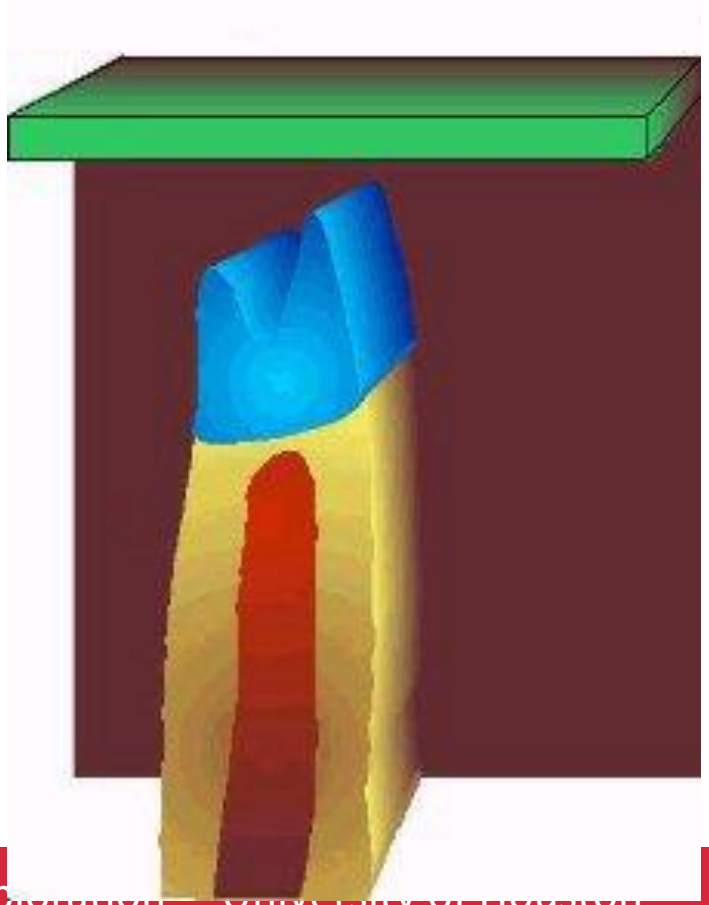
Basic Experiment: DC

- **Target:**

  Ore body. Mineralized regions less resistive than host

Elura Orebody Electrical resistivities

Rock Type	*Ohm-m*
Overburden	12
Host rocks	200
Gossan	420
Mineralization (pyritic)	0.6
Mineralization (pyrrhotite)	0.6



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Basic Experiment: DC

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- **Setup:**

  Tx: Current electrodes

  Rx: Potential electrodes

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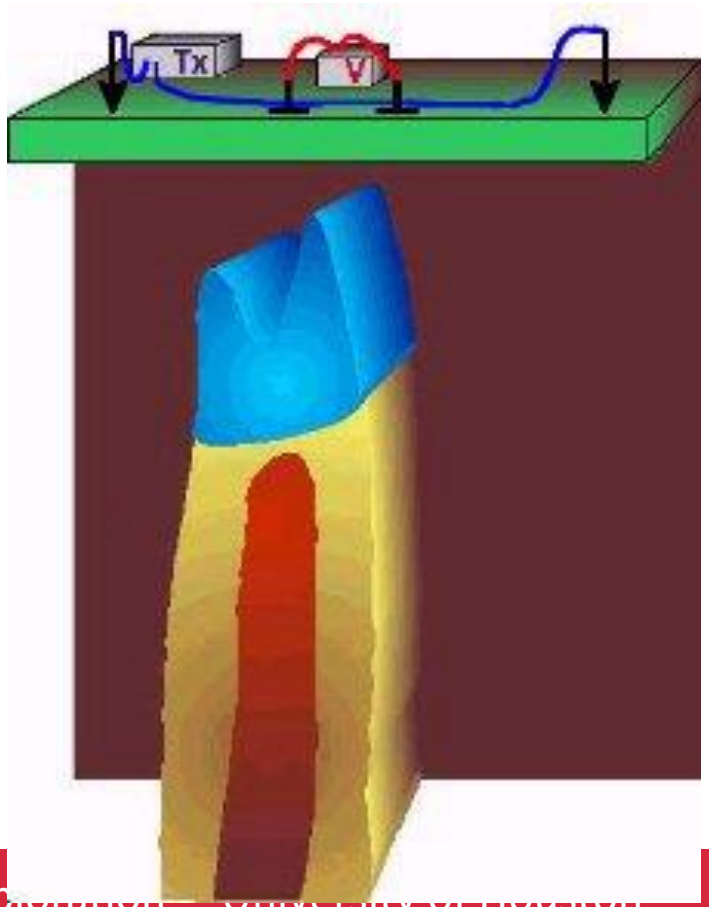

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Basic Experiment: DC

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  Preferentially flow through conductors

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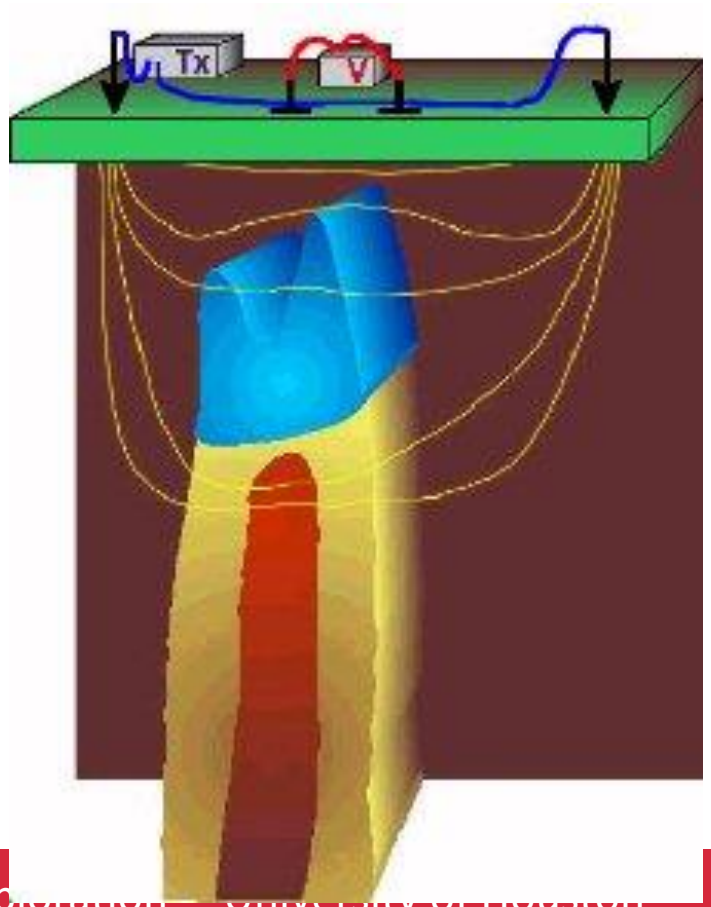

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- **Charges:**

  Build up at interfaces

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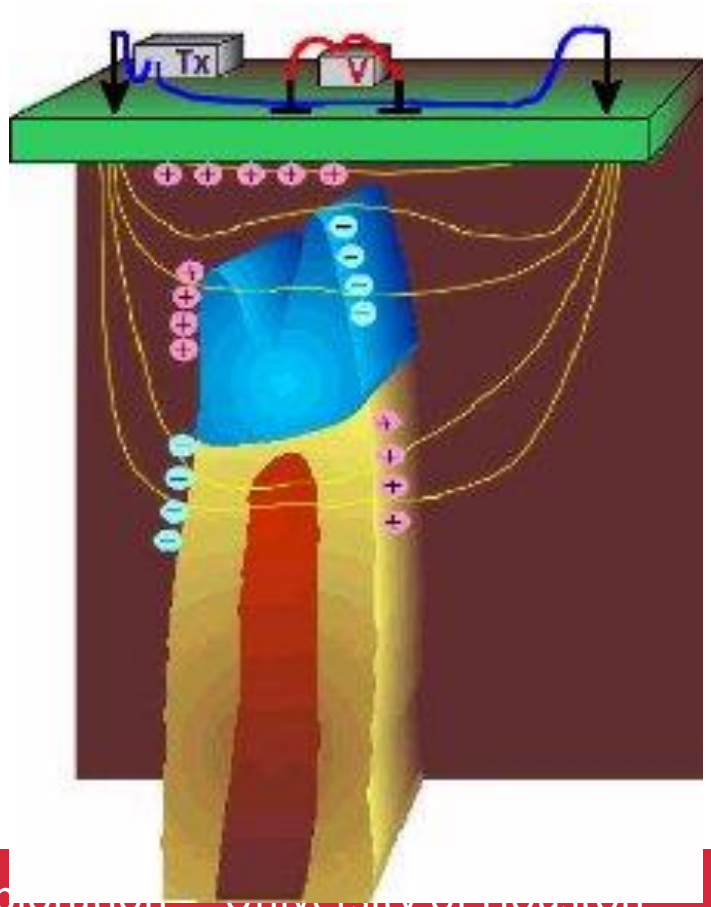

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Basic Experiment: DC

- **Target:**

  Ore body. Mineralized regions less resistive than host

- **Setup:**

  Tx: Current electrodes

  Rx: Potential electrodes

- **Currents:**

  Preferentially flow through conductors

- **Charges:**

  Build up at interfaces

- **Potentials:**

  Associated with the charges are measured at the surface

Elura Orebody Electrical resistivities

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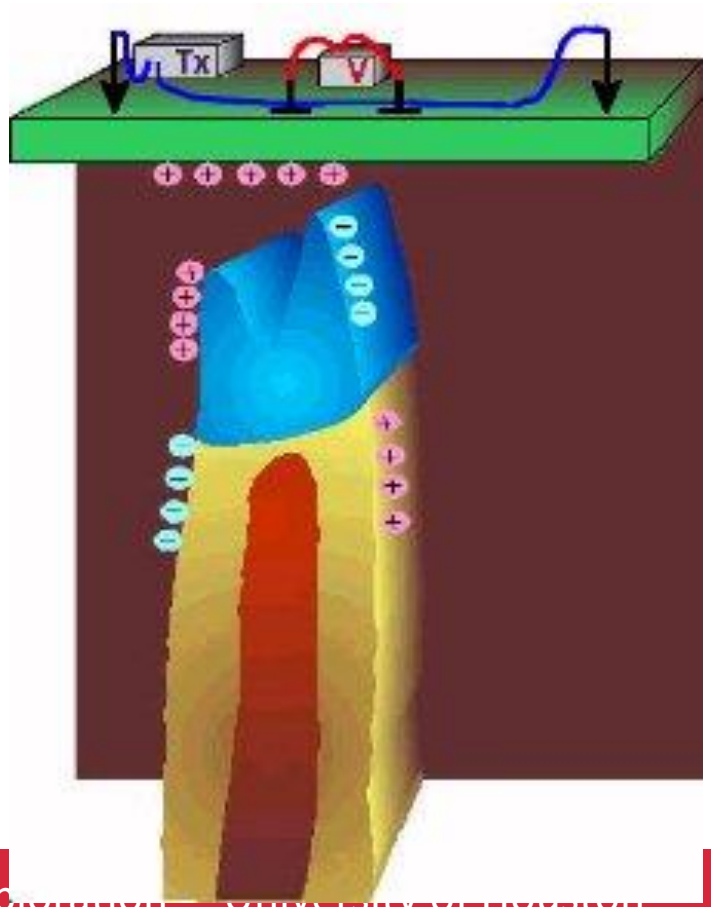
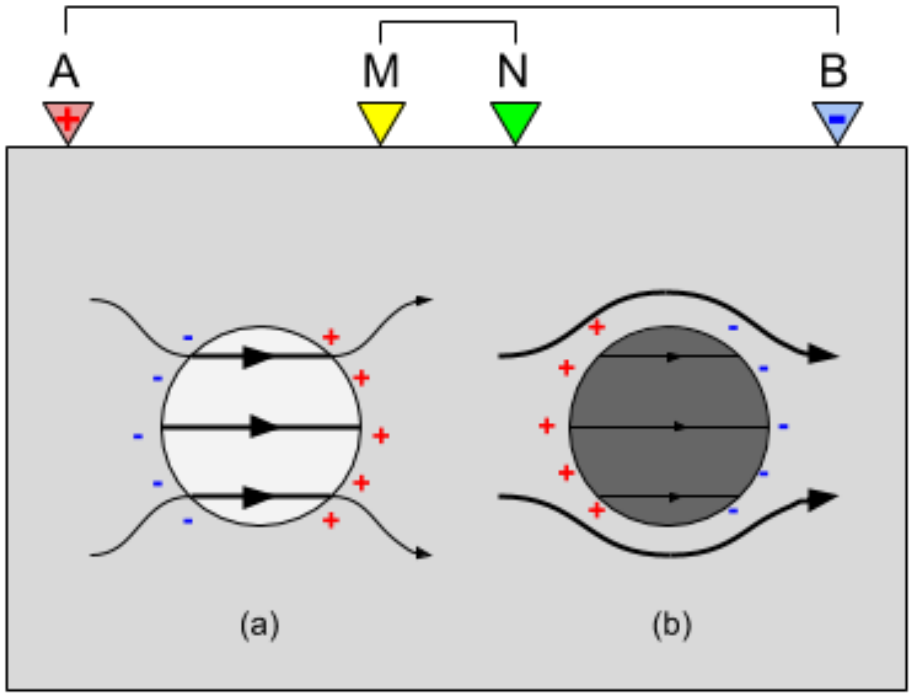


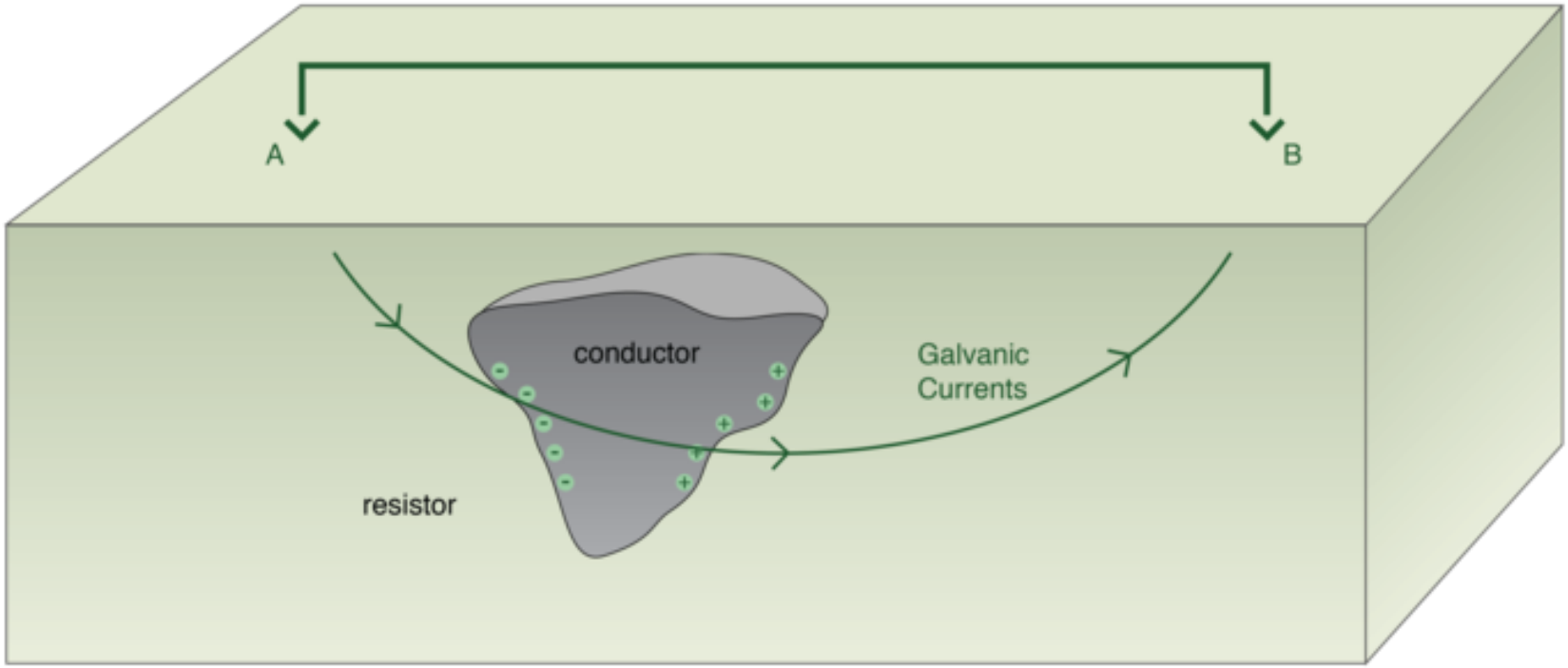
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Charges on a resistor and conductor: DC



Direct Current Resisitivity (DCR) experiment showing current path and charge built up near a (a) conductive and (b) resistive anomaly. Image Courtesy: https://em.geosci.xyz/content/geophysical_surveys/dcr/index.html

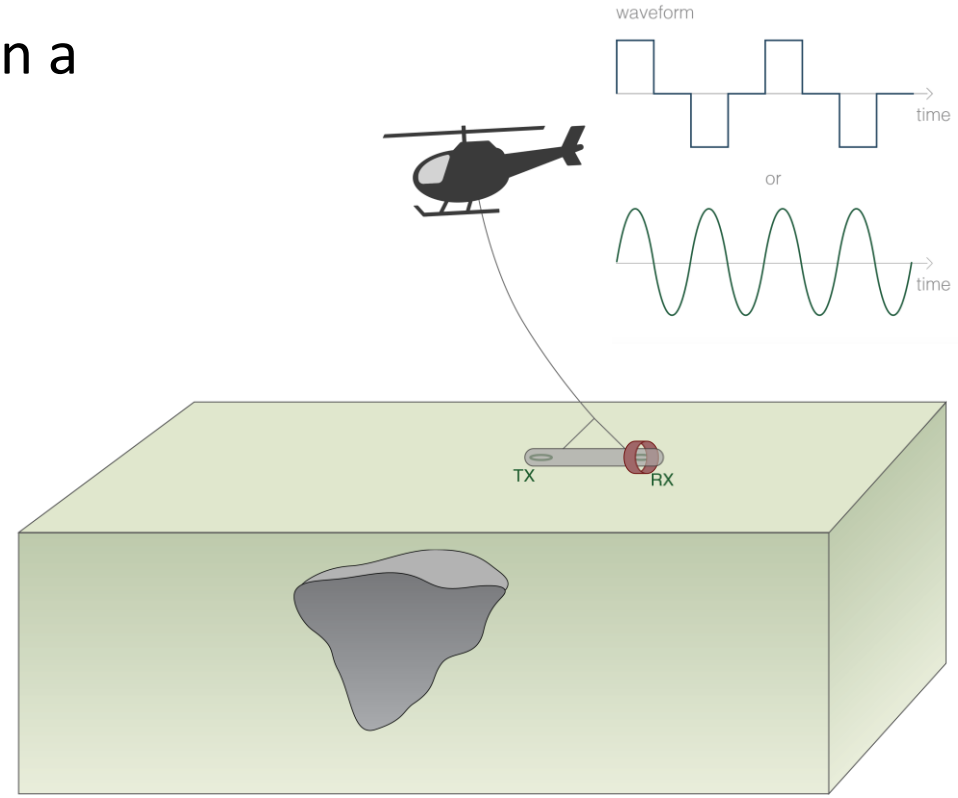
Recap: DC survey



Galvanic currents: the electric current flows in a constant direction (the direction does not change with time)

Basic Experiment: EM with inductive sources

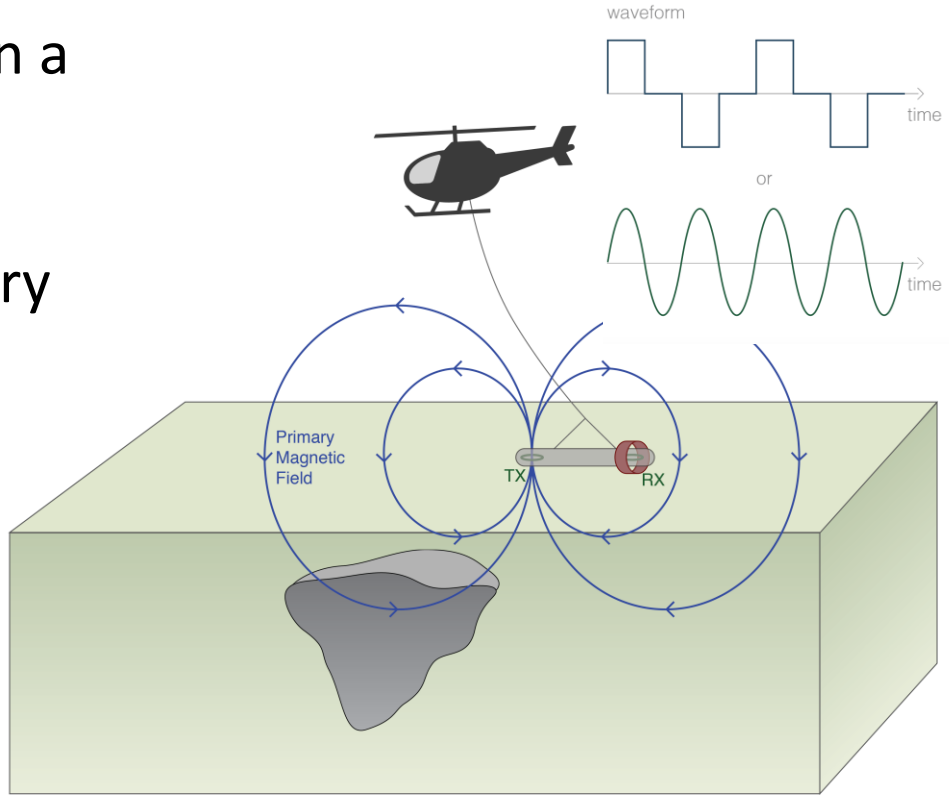
- **Setup:**
  - transmitter and receiver are in a towed bird



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Basic Experiment: EM with inductive sources

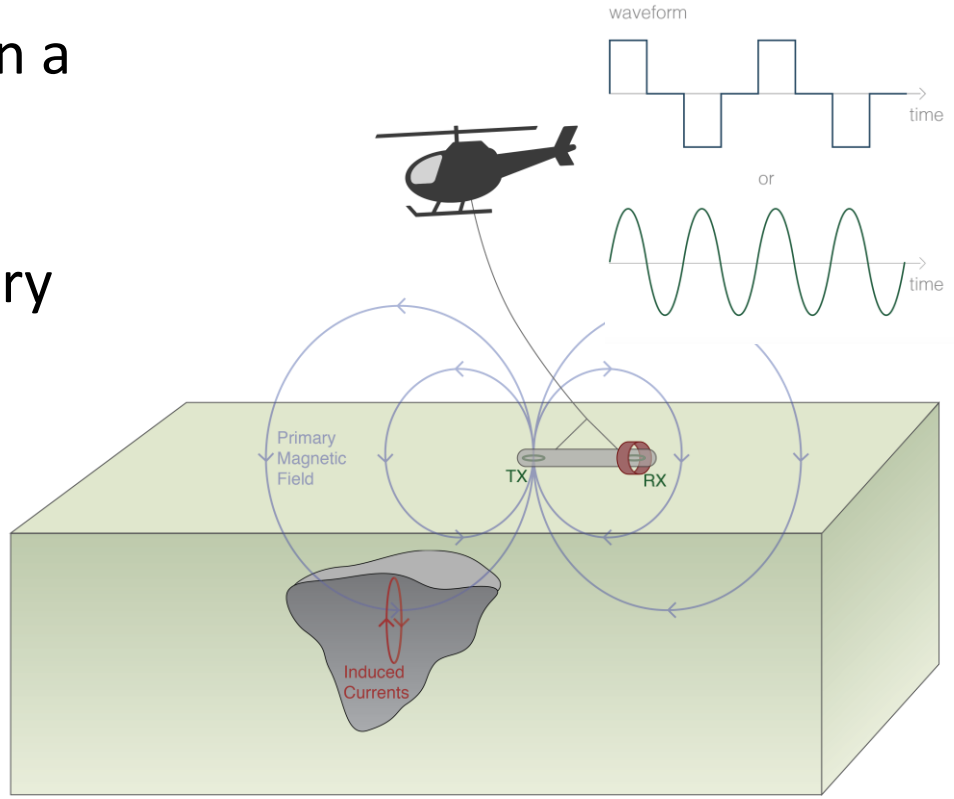
- **Setup:**
  - transmitter and receiver are in a towed bird
- **Primary:**
  - Transmitter produces a primary magnetic field



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Basic Experiment: EM with inductive sources

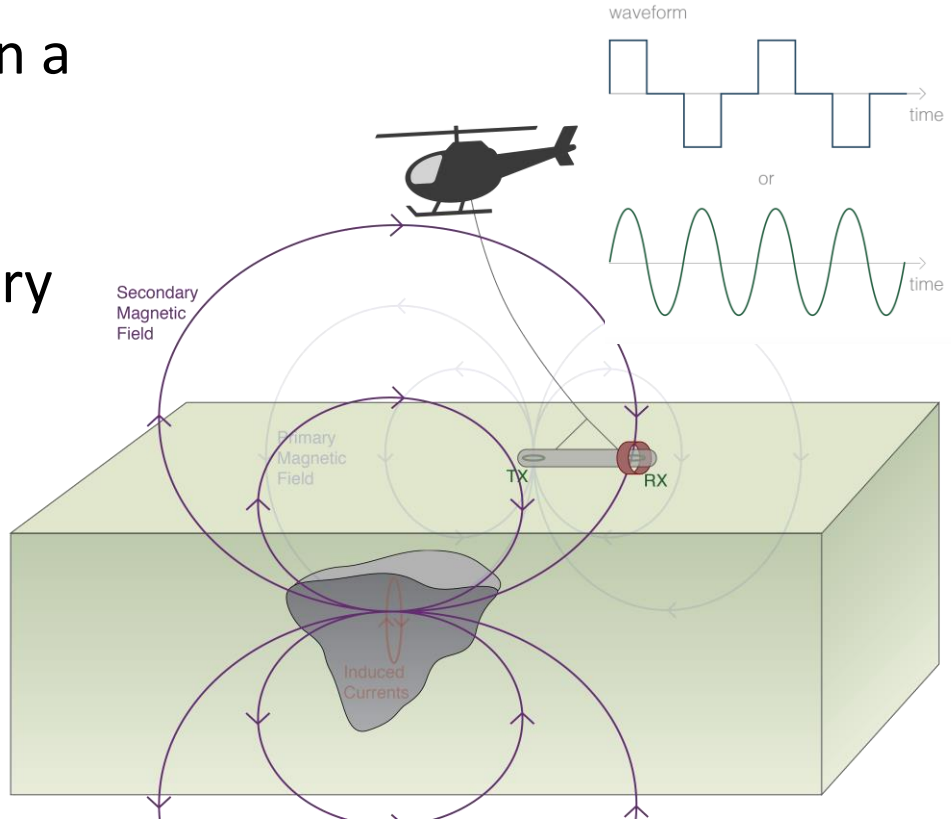
- **Setup:**
  - transmitter and receiver are in a towed bird
- **Primary:**
  - Transmitter produces a primary magnetic field
- **Induced Currents:**
  - Time varying magnetic fields generate electric fields everywhere and currents in conductors



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Basic Experiment: EM with inductive sources

- **Setup:**
  - transmitter and receiver are in a towed bird
- **Primary:**
  - Transmitter produces a primary magnetic field
- **Induced Currents:**
  - Time varying magnetic fields generate electric fields everywhere and currents in conductors
- **Secondary Fields:**
  - The induced currents produce a secondary magnetic field.



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

From DC and inductive source to grounded source

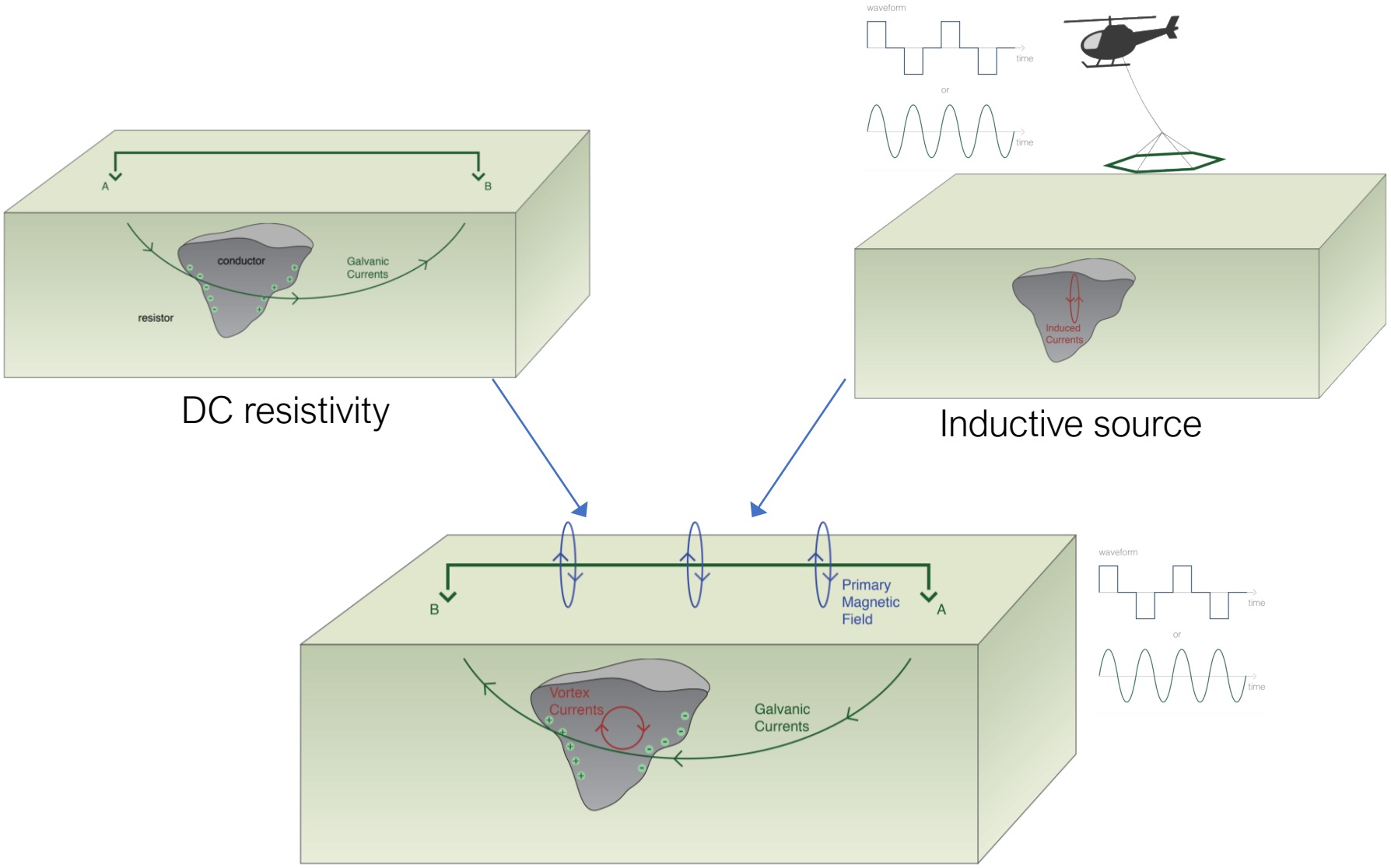


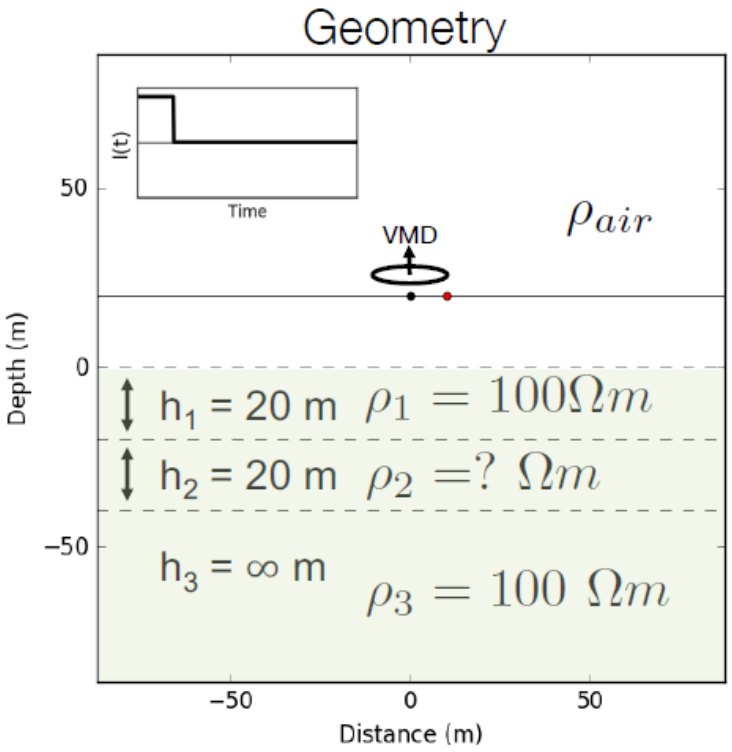
Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Question

- Why bother with grounded sources?
- What is wrong with inductive source EM?

EM with inductive source: Layered earth model

- 3 layers + air,
- ρ_2 varies



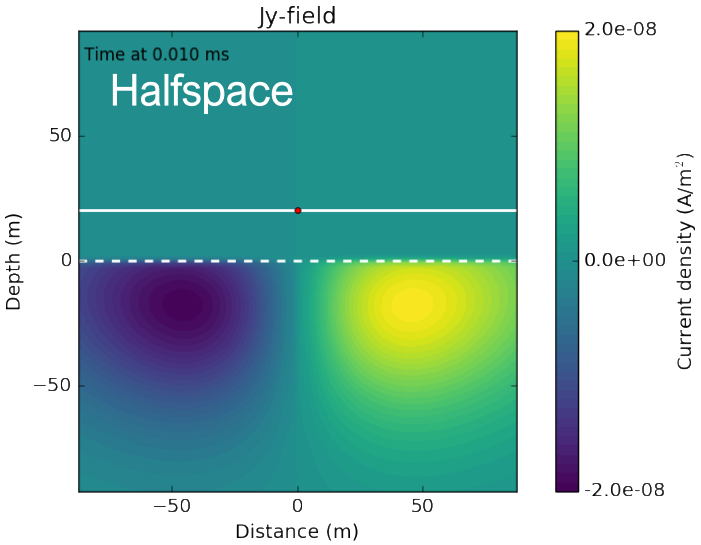
- Four different cases:
  - Halfspace
    ρ_2 = 100 Ωm
  - Resistive
    ρ_2 = 1000 Ωm
  - Conductive
    ρ_2 = 10 Ωm
  - Very conductive
    ρ_2 = 1 Ωm

- Fields
  - j_y off-time
  - b off-time

Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Layered earth currents (j_y)

ρ_2 = 100 Ωm



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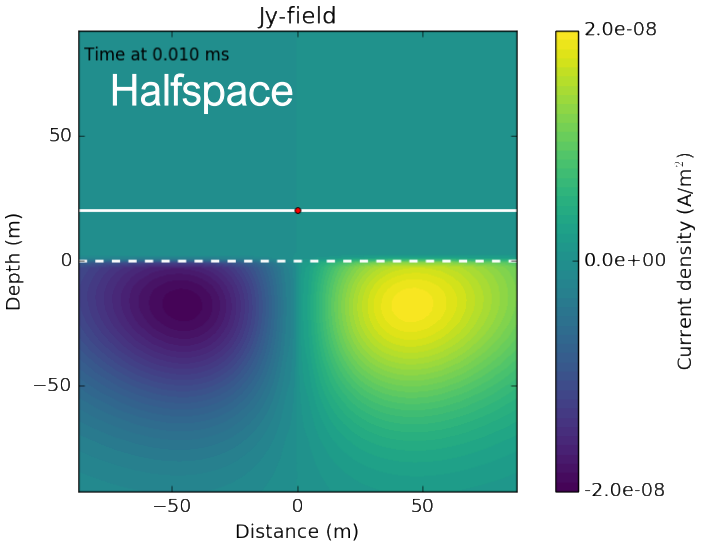

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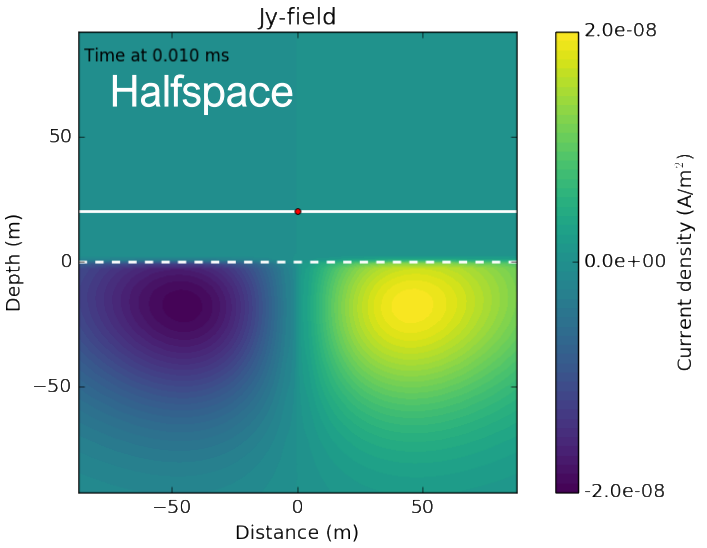

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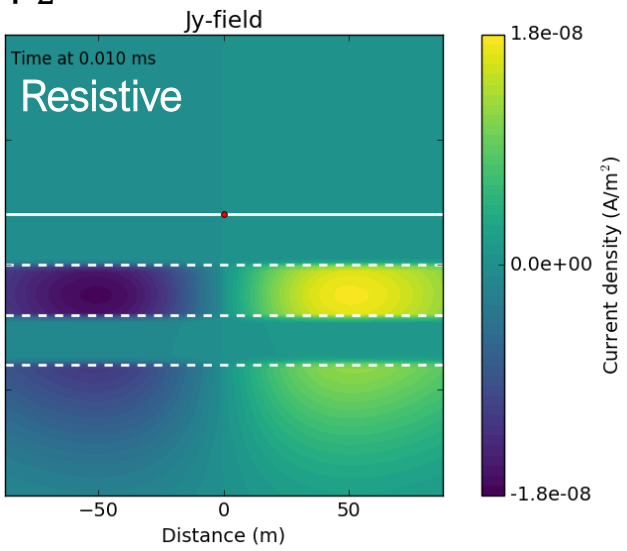

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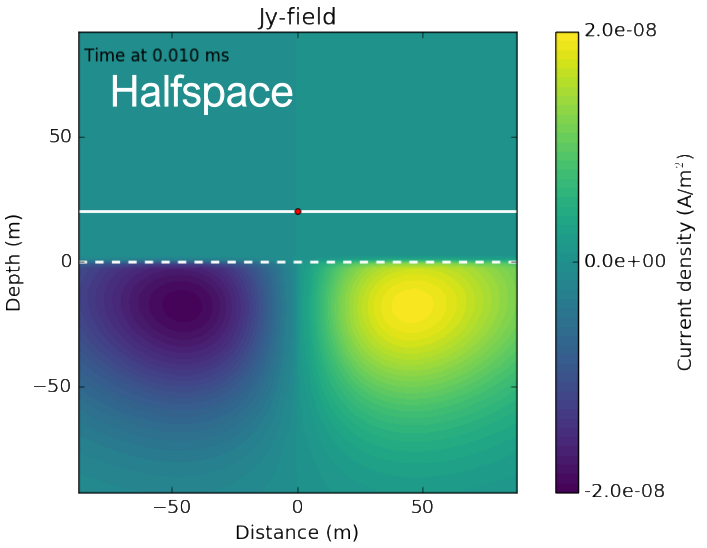

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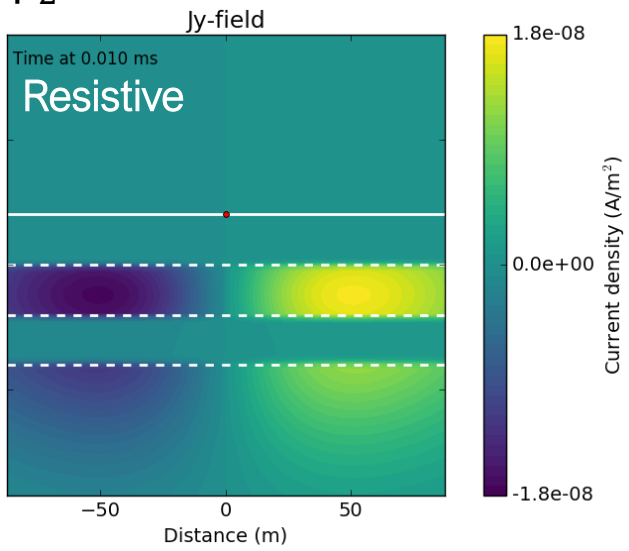

ρ_2 = 10 Ωm

Layered earth currents (j_y)

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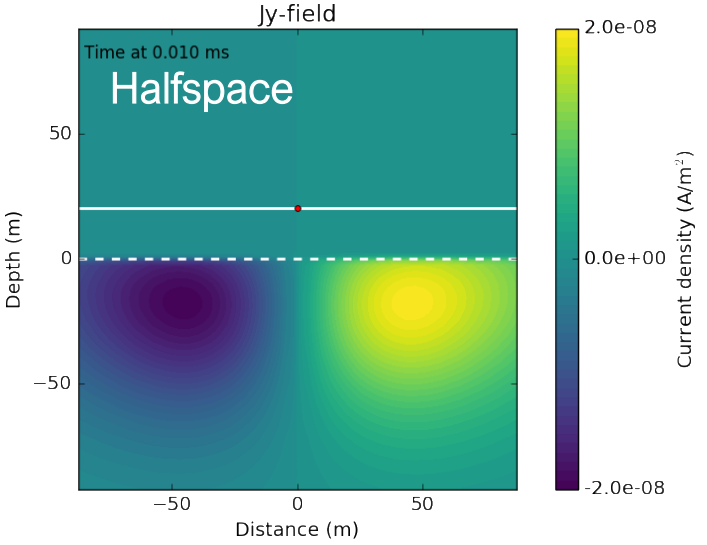

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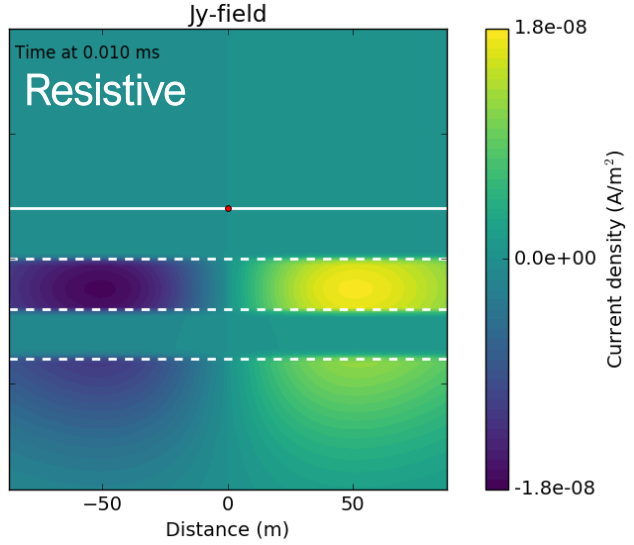

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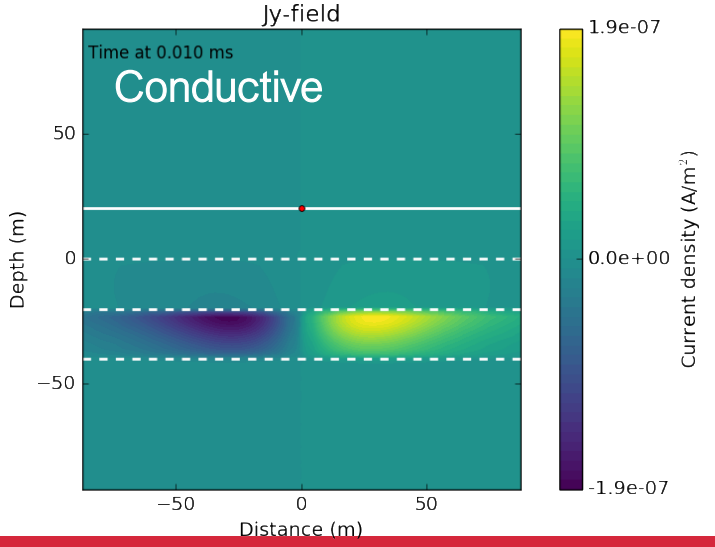

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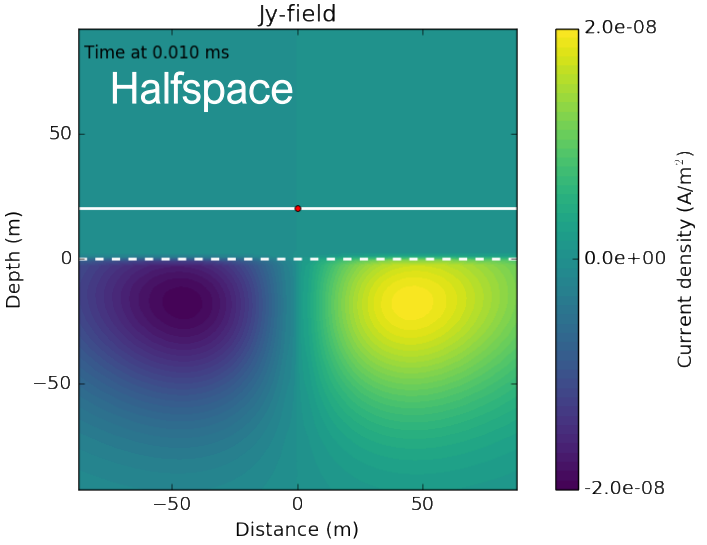

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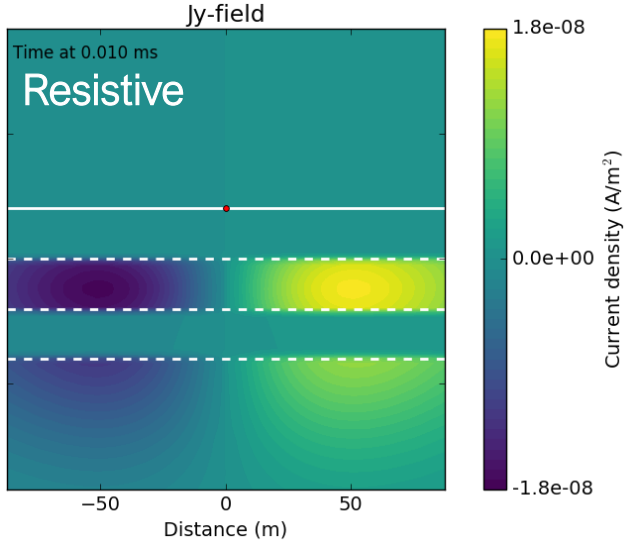

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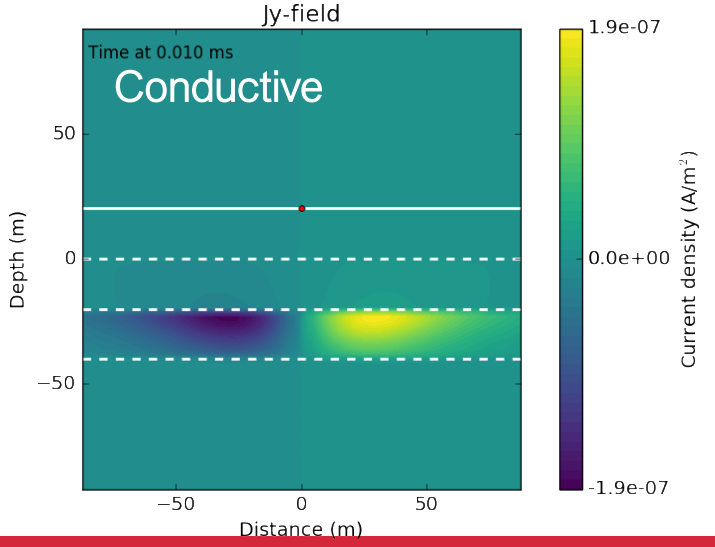
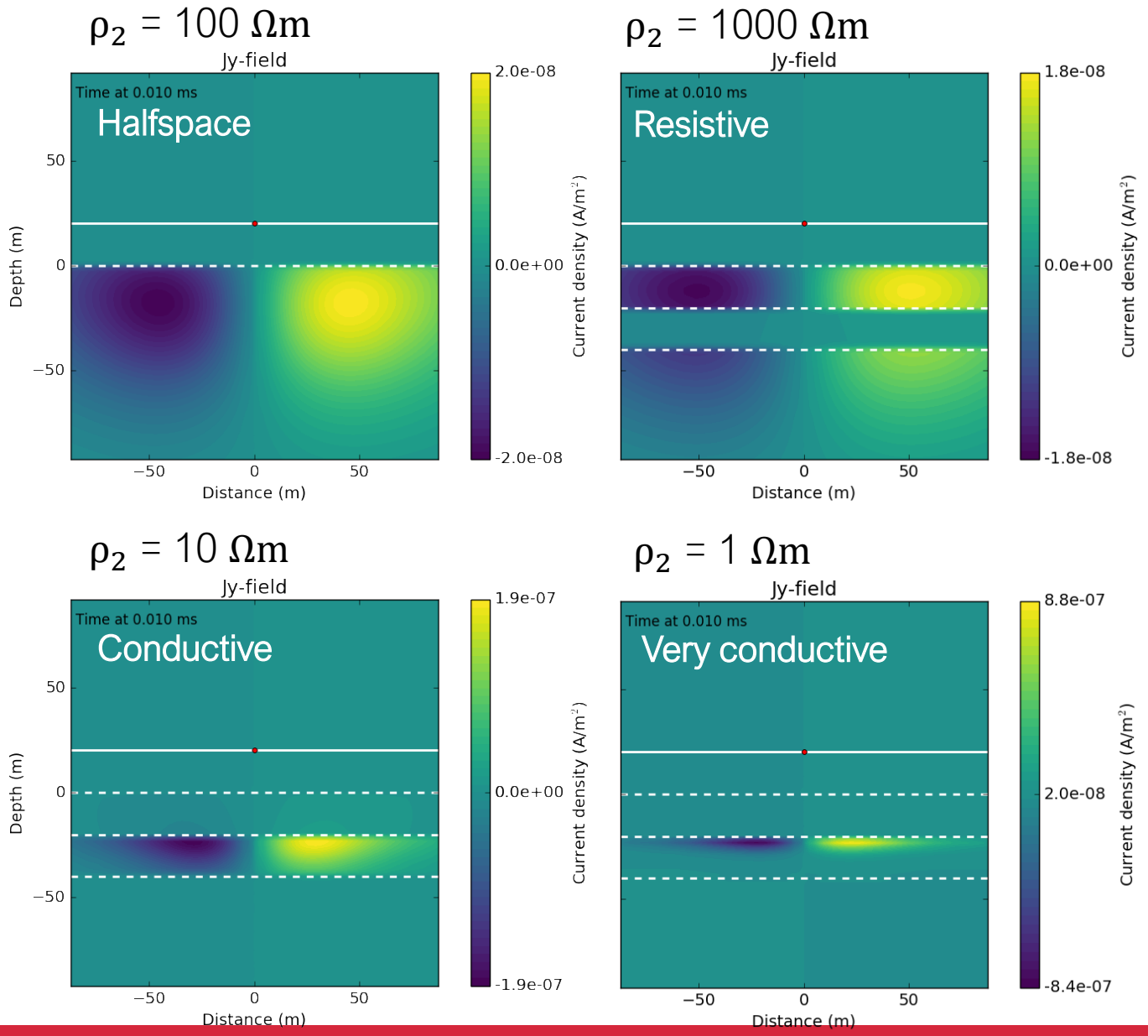
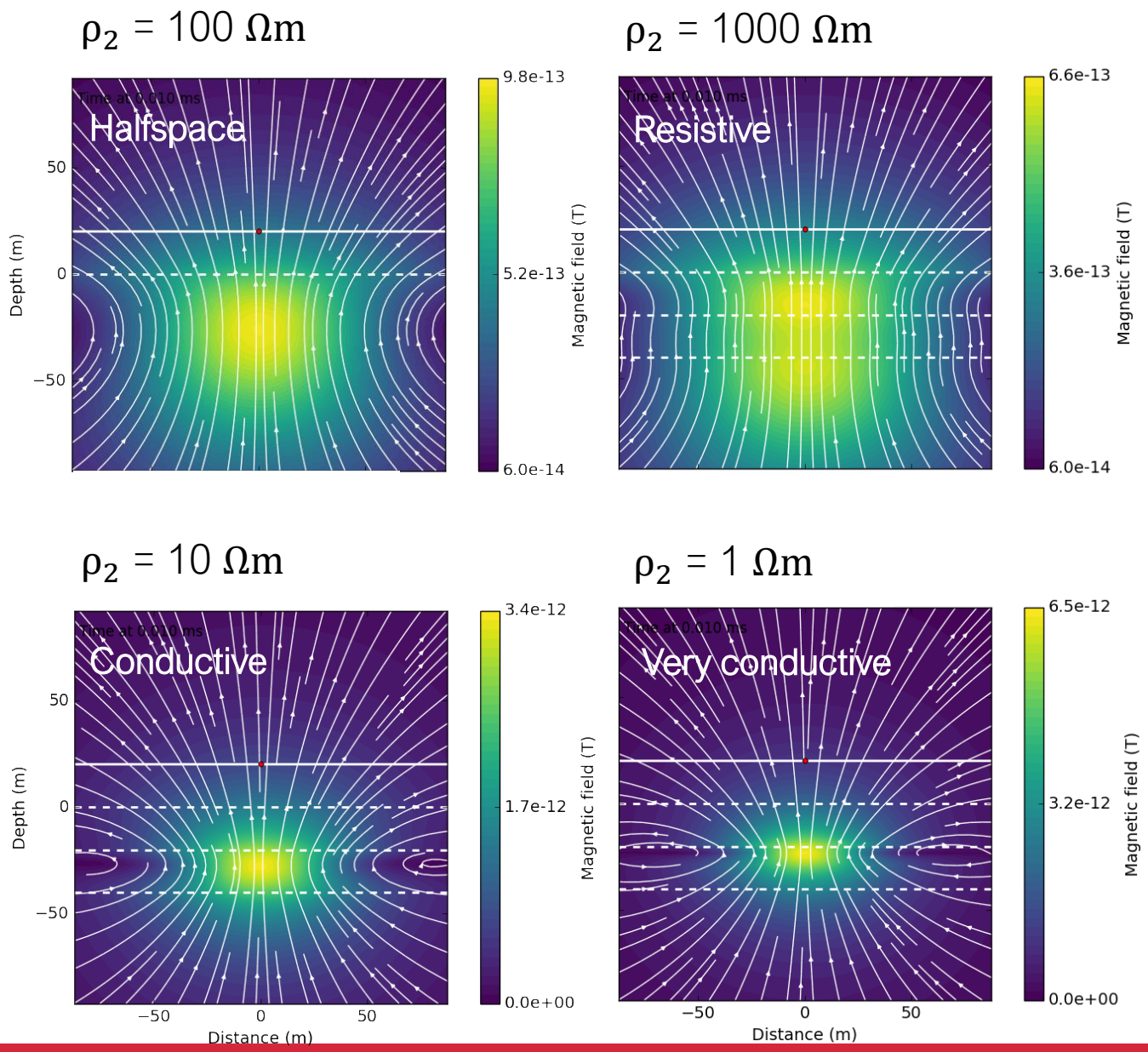


ρ_2 = 1 Ωm

Layered earth currents (j_y)

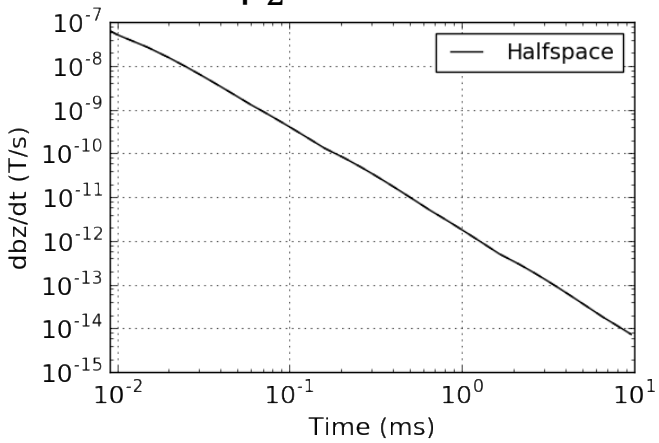


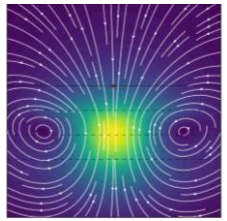
Layered earth mag. fields (b)



db_z/dt sounding curves

ρ_2 = 100 Ωm





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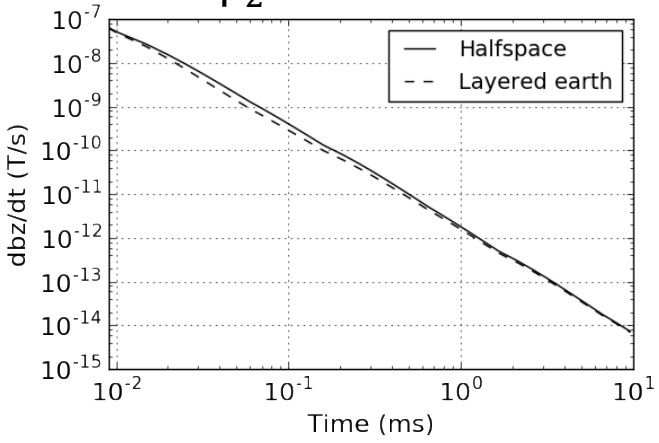

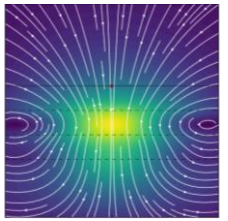

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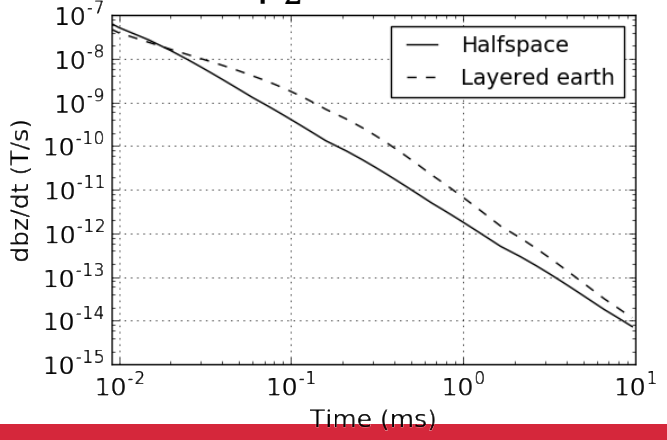

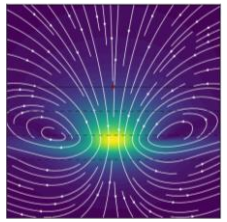

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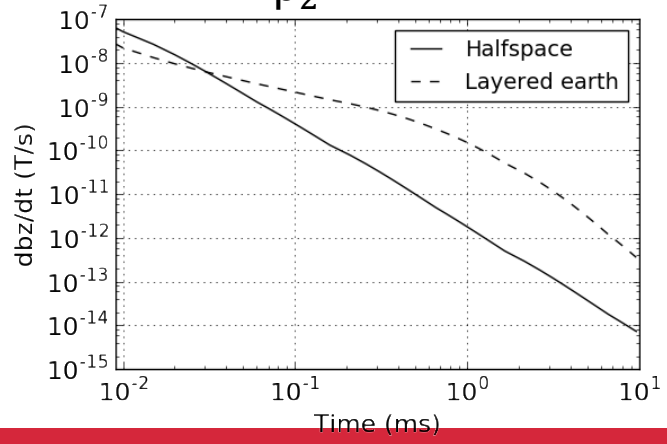
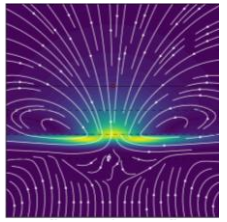




Observations

- EM signal decays slower in more conductive medium
- EM with inductive sources very sensitive to conductors (not so sensitive to resistors)

Question

- What if our target is a resistor?

Question

- What if our target is a resistor?

- Can you think of anything in geoscience that is resistive and of great economic value?

Question

- What if our target is a resistor?
- Can you think of anything in geoscience that is resistive and of great economic value?
- Write it down on a piece of paper.

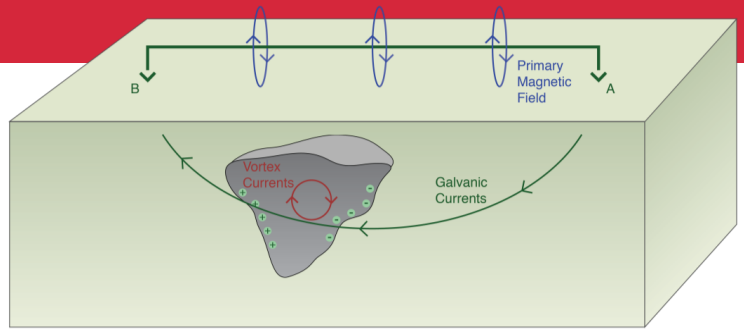
Question

- What if our target is a resistor?
- Can you think of anything in geoscience that is resistive and of great economic value?
- Hydrocarbon, gas hydrate …

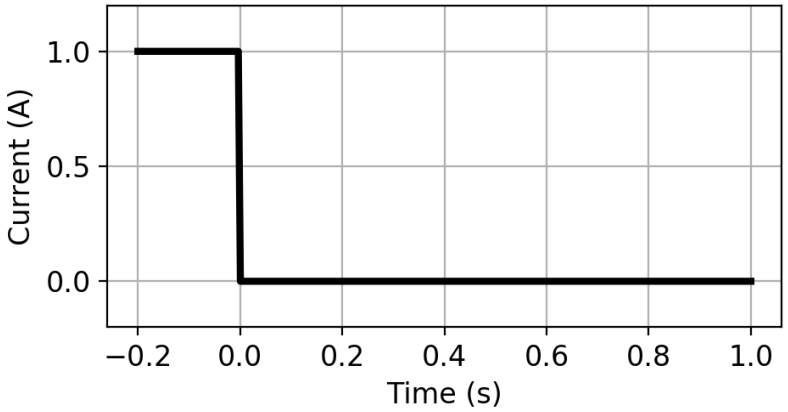
Answer

- This is why we are studying EM with grounded sources!

TDEM vs. FDEM

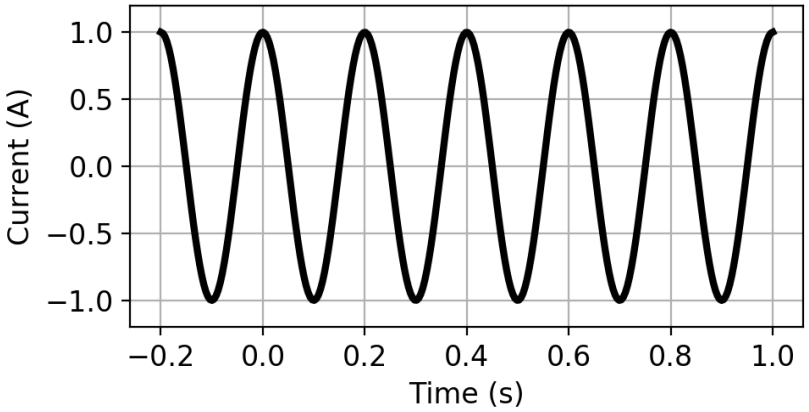


Step-off



- Waveform: Shut off
- No primary
- Measure in “Off-time”

Harmonic

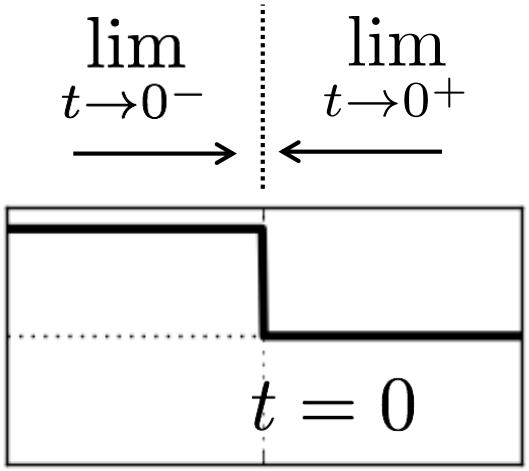


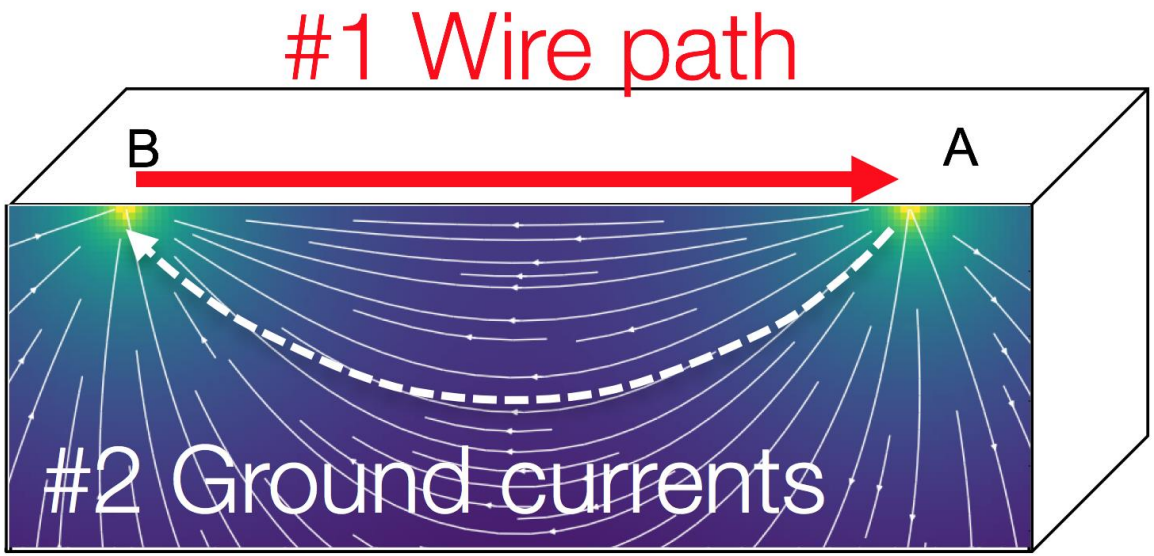
- Waveform: harmonic
- Primary always on
- Data partitioned into
  - Real (In-phase)
  - Imag (Quadrature)

Let us consider TDEM with grounded sources

Currents: Grounded System

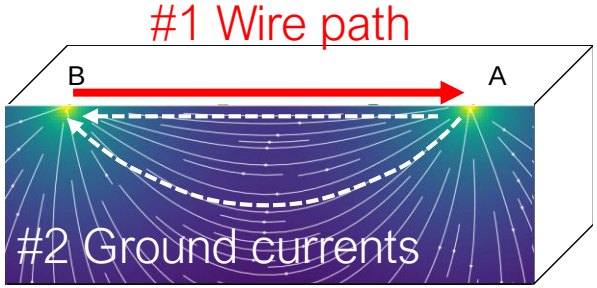
- t = 0^- Steady state
- t = 0 Shut off current
- t = 0^+ Off-time

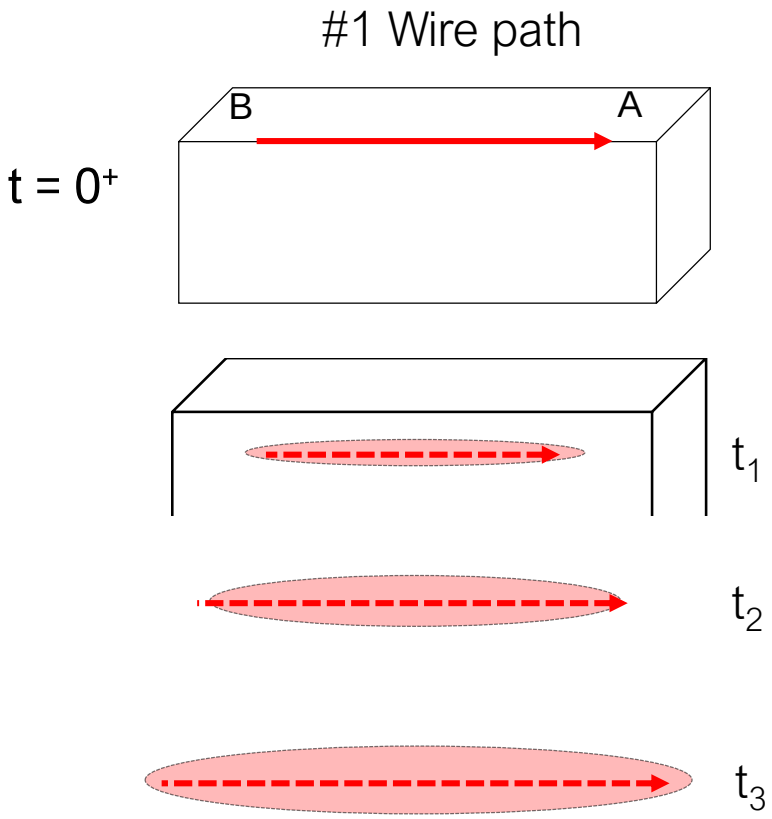




What happens when we shut the system off?

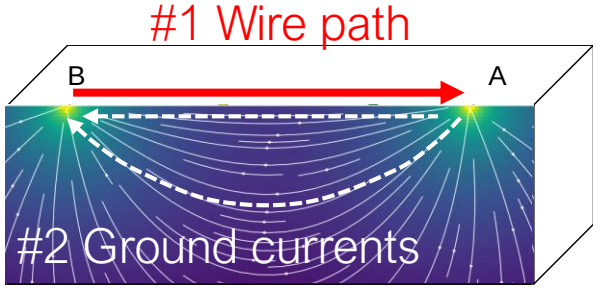
Currents: Grounded System



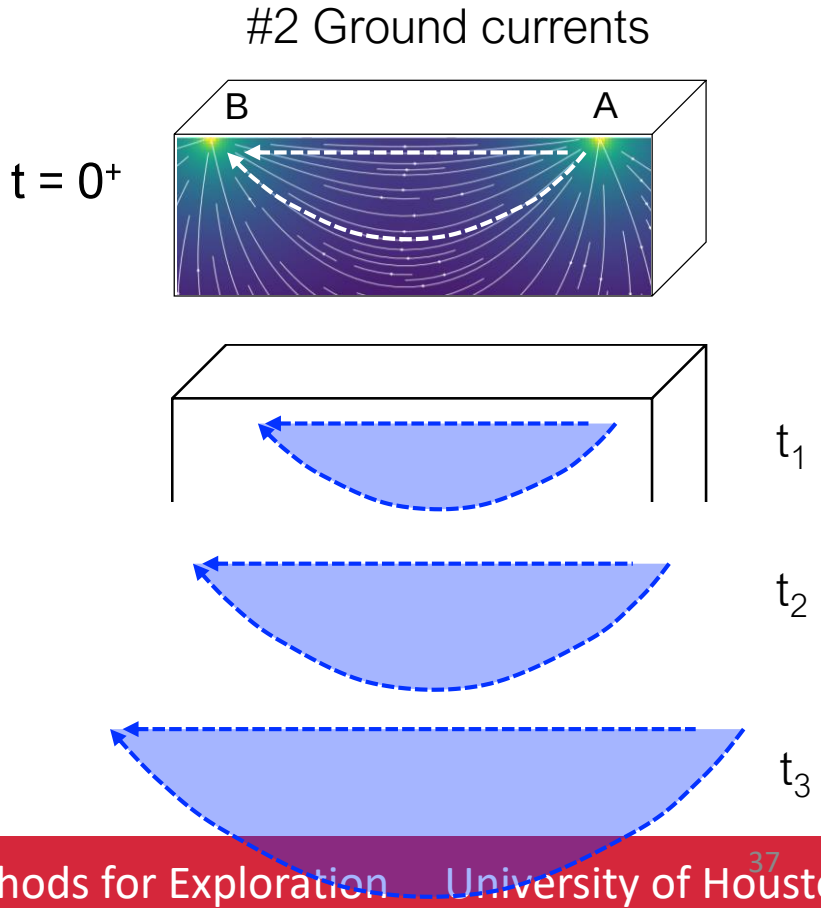


- Immediately after shut off: image current at the surface
- Successive time: currents diffuse downwards and outwards

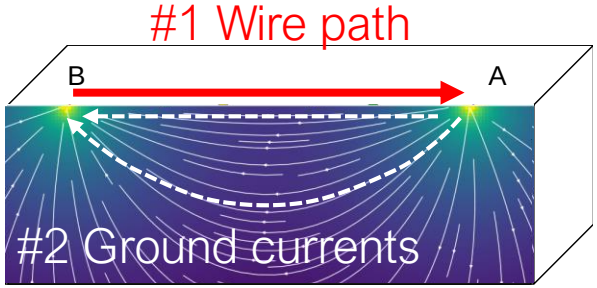
Currents: Grounded System



- Immediately after shut off: ground currents are still there
- Successive time: currents diffuse downwards and outwards

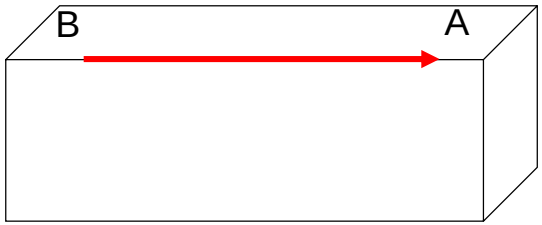


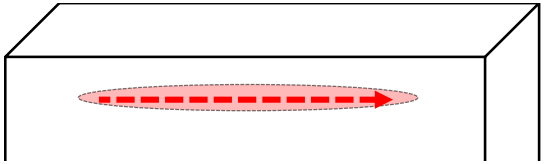
Currents: Grounded System



#1 Wire path

t = 0+





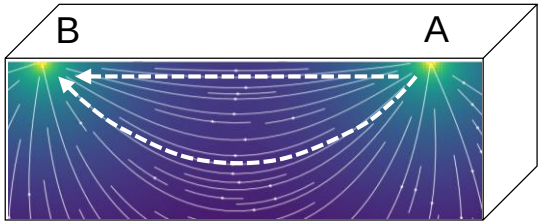
t_1

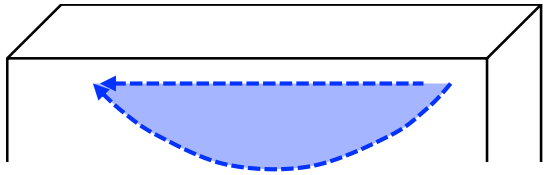
t_2

t_3

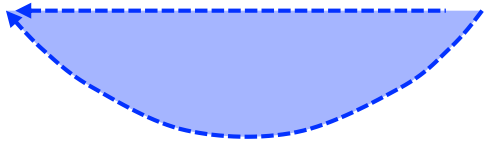
#2 Ground currents

t = 0+

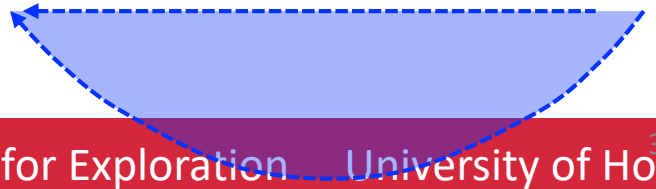




t_1



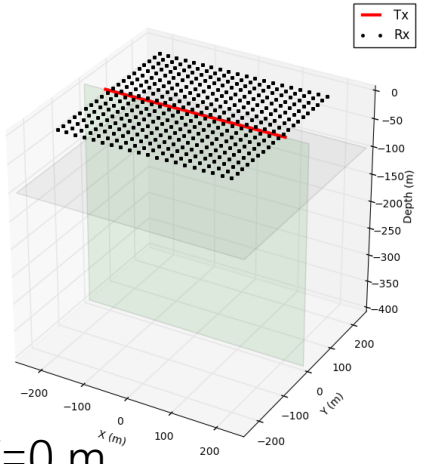
t_2



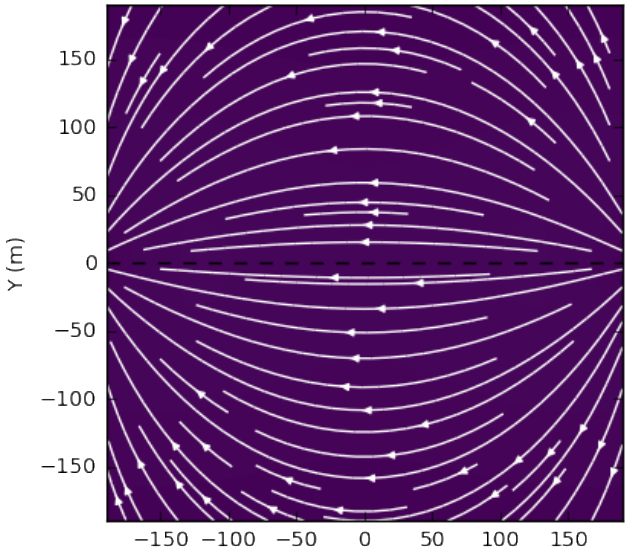
t_3

Grounded Source: Halfspace Currents

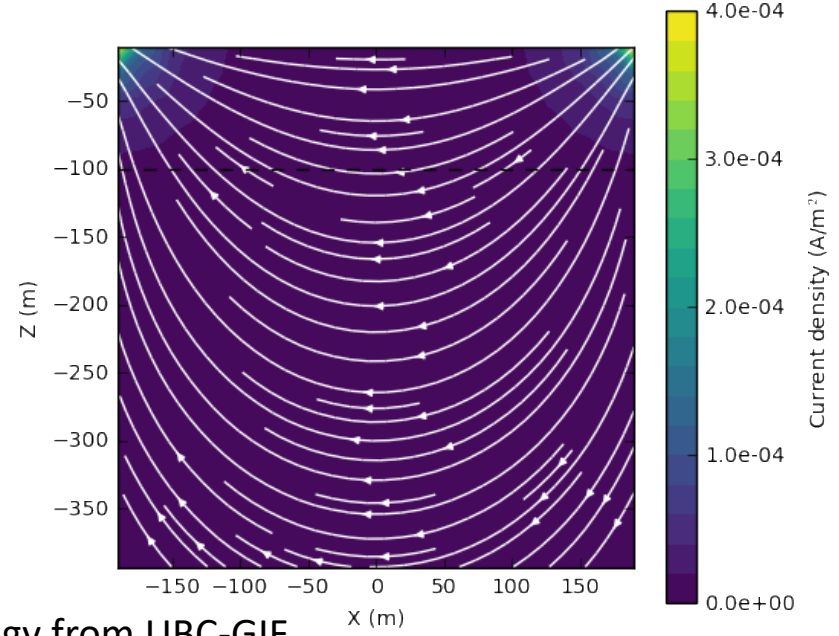
- Parameters:
  - halfspace (0.01 S/m)
  - $t=0^-$, steady state



XY plane at Z=-100 m



XZ plane at Y=0 m

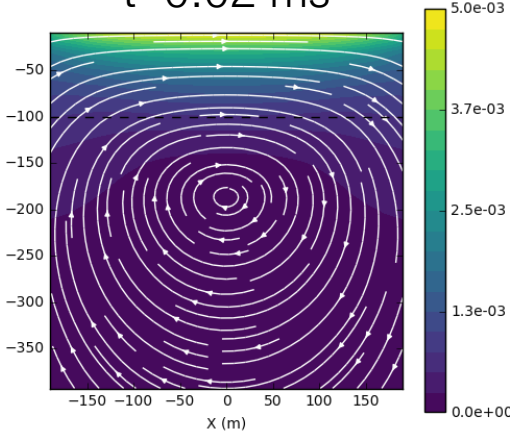


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

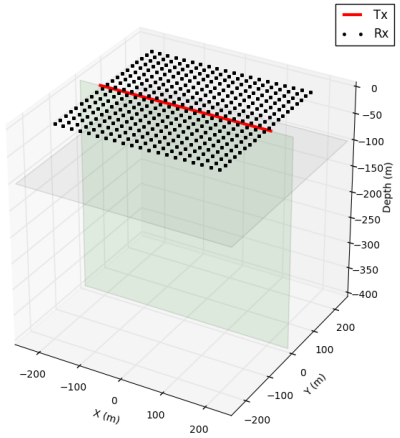
Grounded Source: Halfspace Currents

- Cross section of currents, t = 0.04 to 10 ms

t=0.02 ms



t=0.04 ms

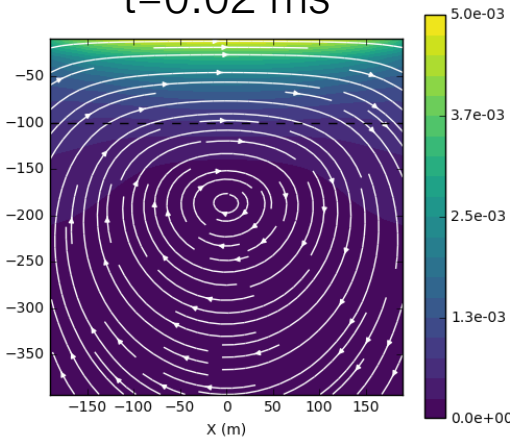


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

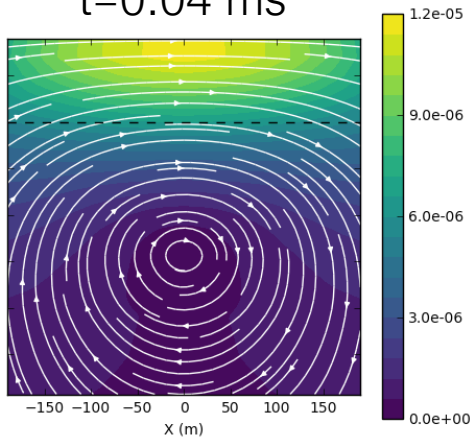
Grounded Source: Halfspace Currents

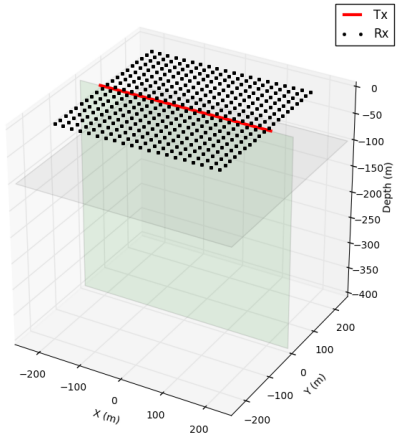
- Cross section of currents, t = 0.04 to 10 ms

t=0.02 ms



t=0.04 ms



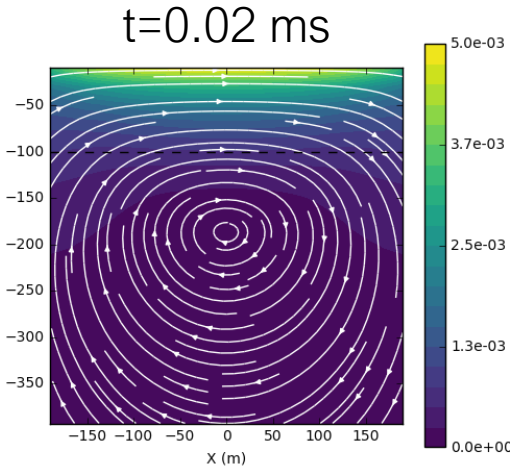


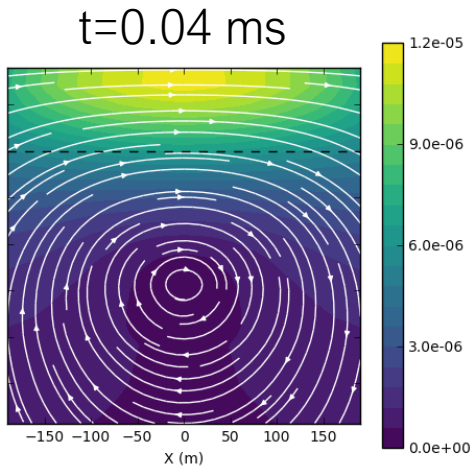
t=0.1 ms

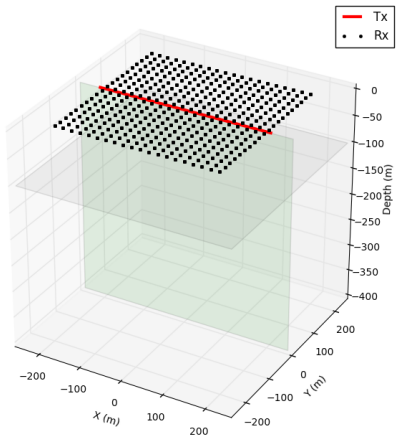
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

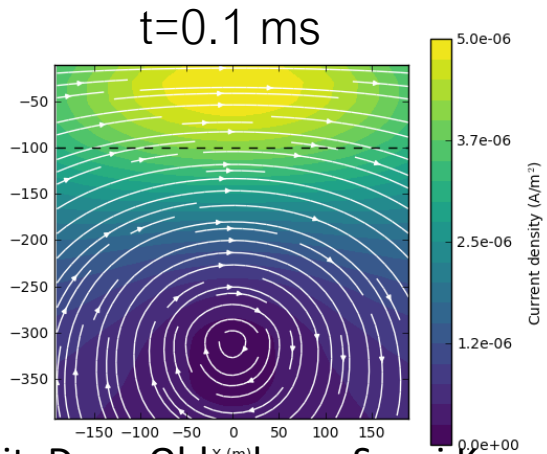
Grounded Source: Halfspace Currents

- Cross section of currents, t = 0.04 to 10 ms







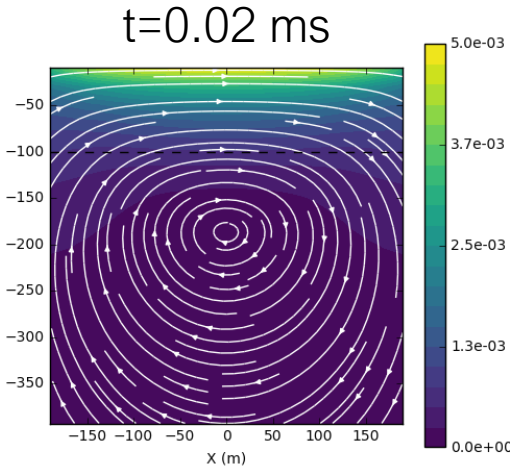


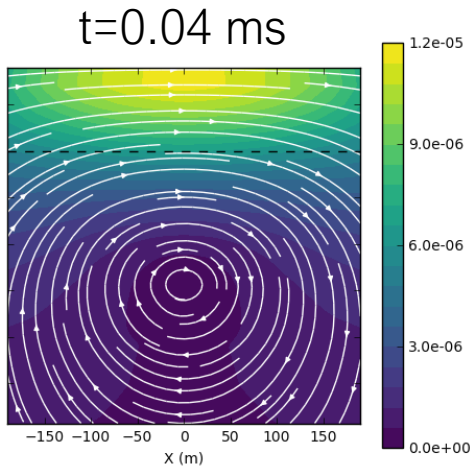
t=1 ms

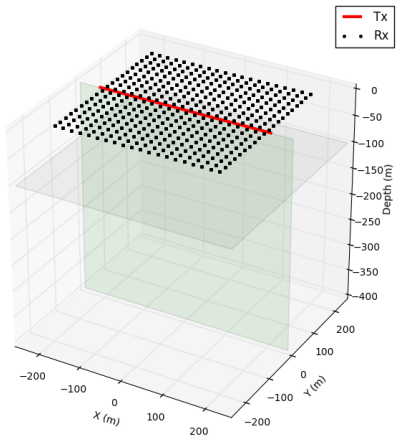
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Grounded Source: Halfspace Currents

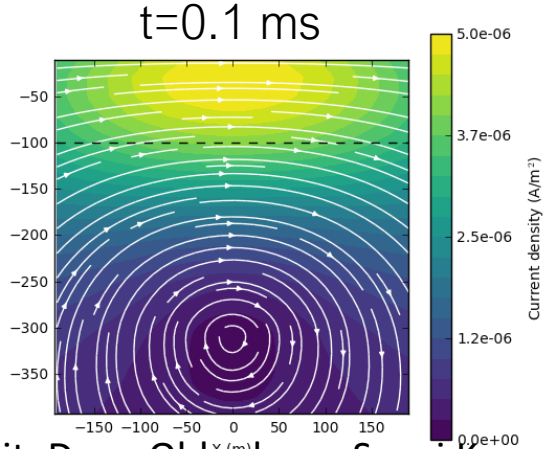
- Cross section of currents, t = 0.04 to 10 ms

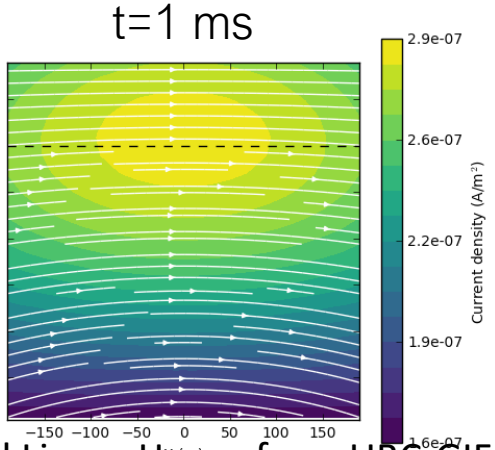






t=10 ms

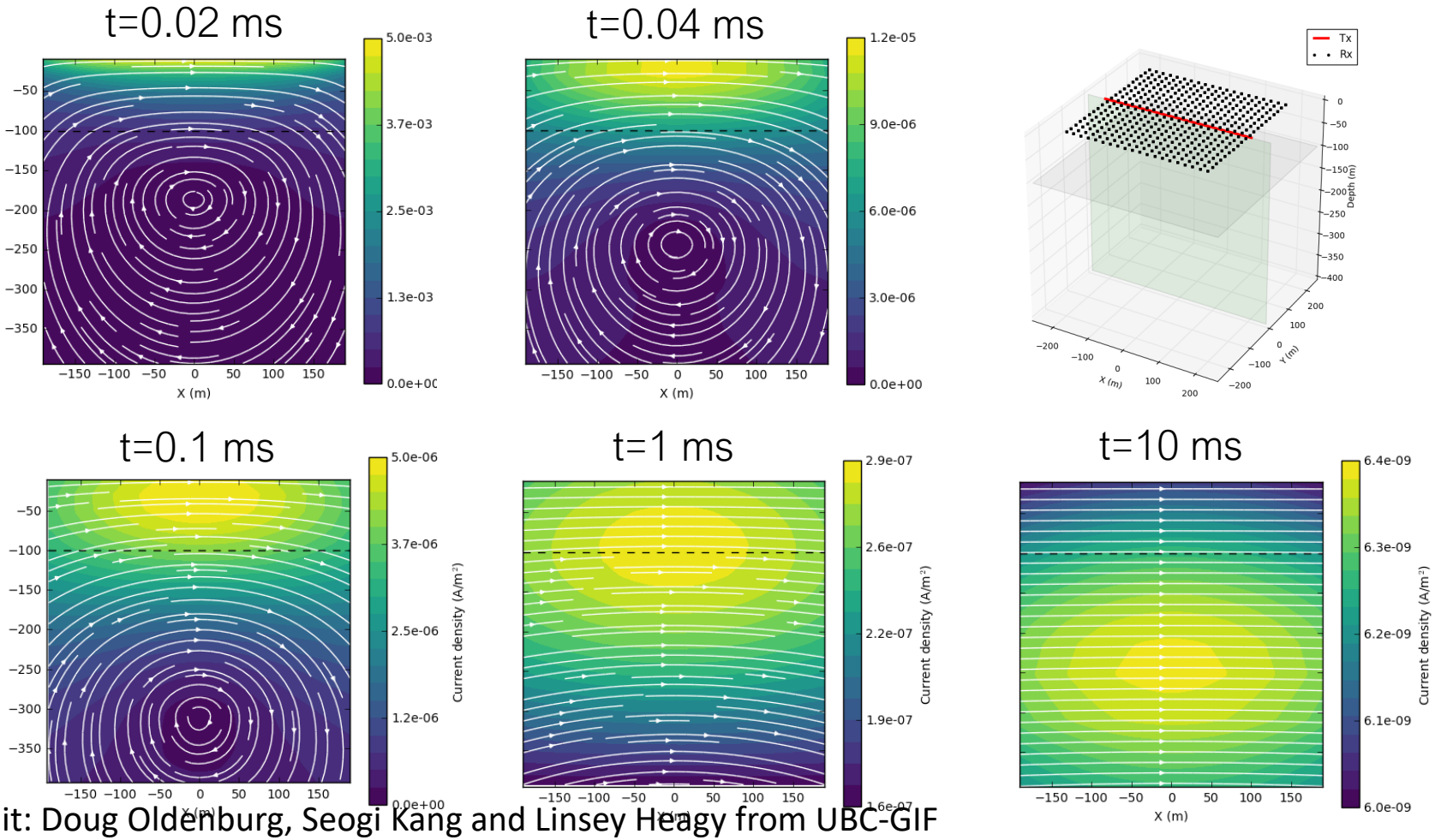




Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Grounded Source: Halfspace Currents

- Cross section of currents, t = 0.04 to 10 ms



Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Comparison with inductive source TDEM

Vertical Magnetic Dipole over a halfspace

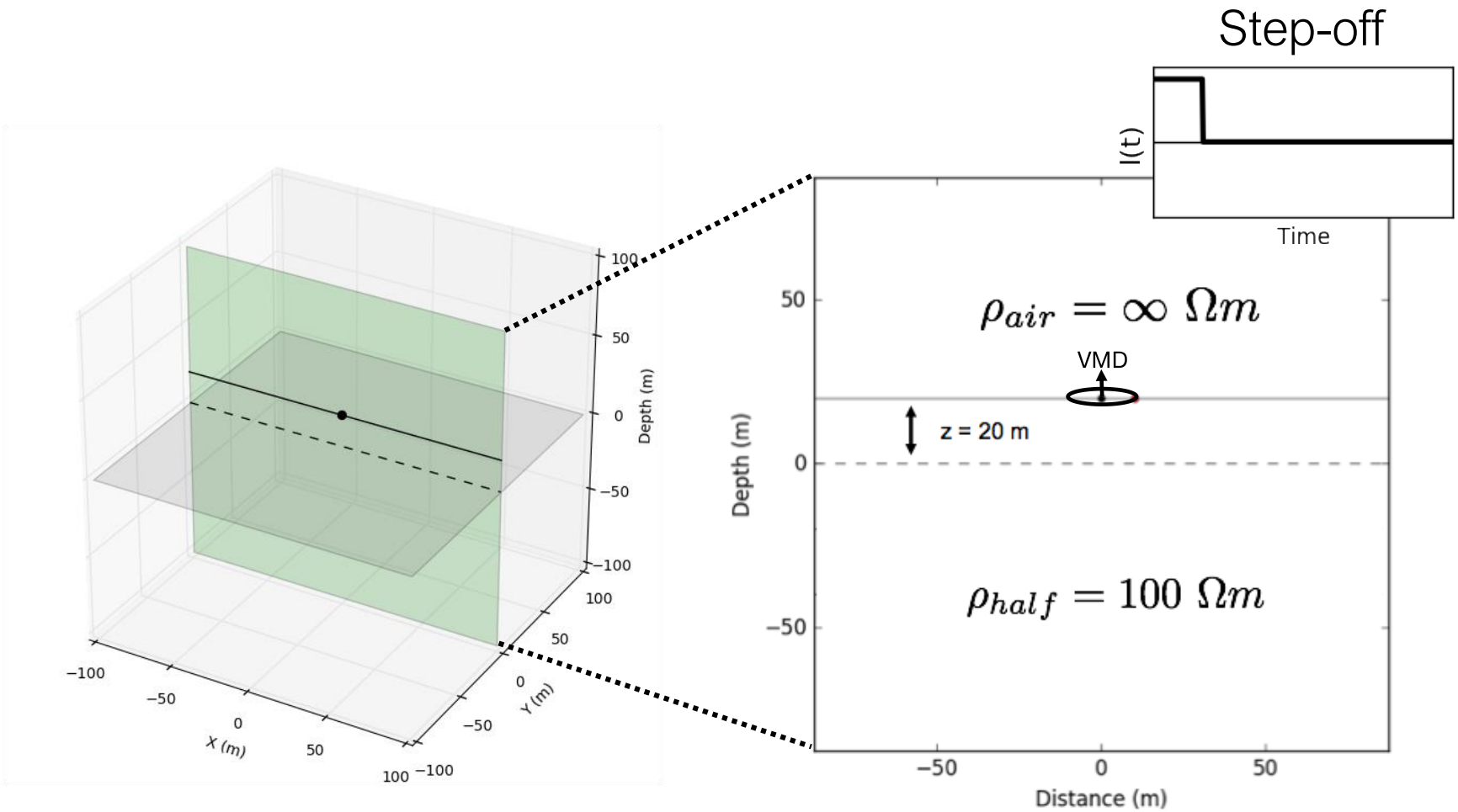


Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Propagation through time

- Time: 0.002ms
- diffusion distance = 18 m

$$d = 1260\sqrt{t\rho}$$

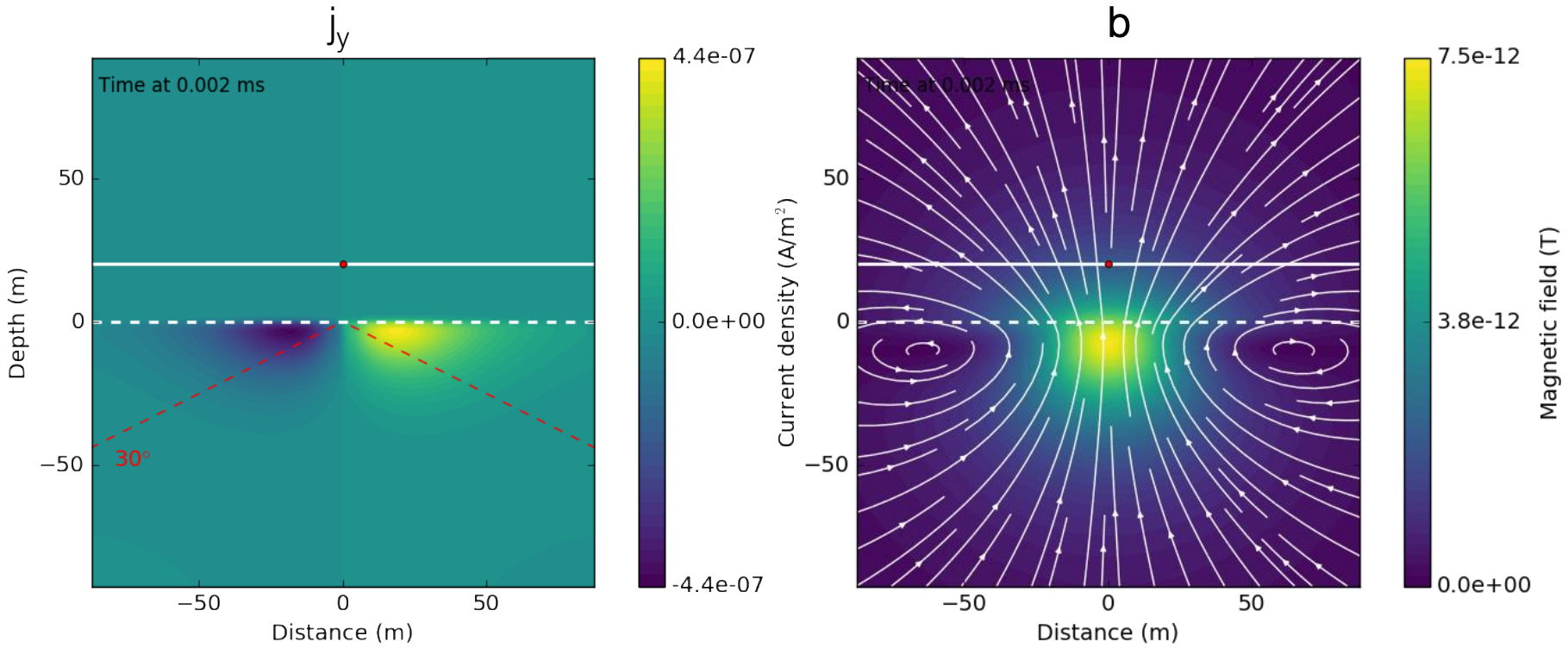


Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Propagation through time

- Time: 0.01ms
- diffusion distance = 38 m

$$d = 1260\sqrt{t\rho}$$

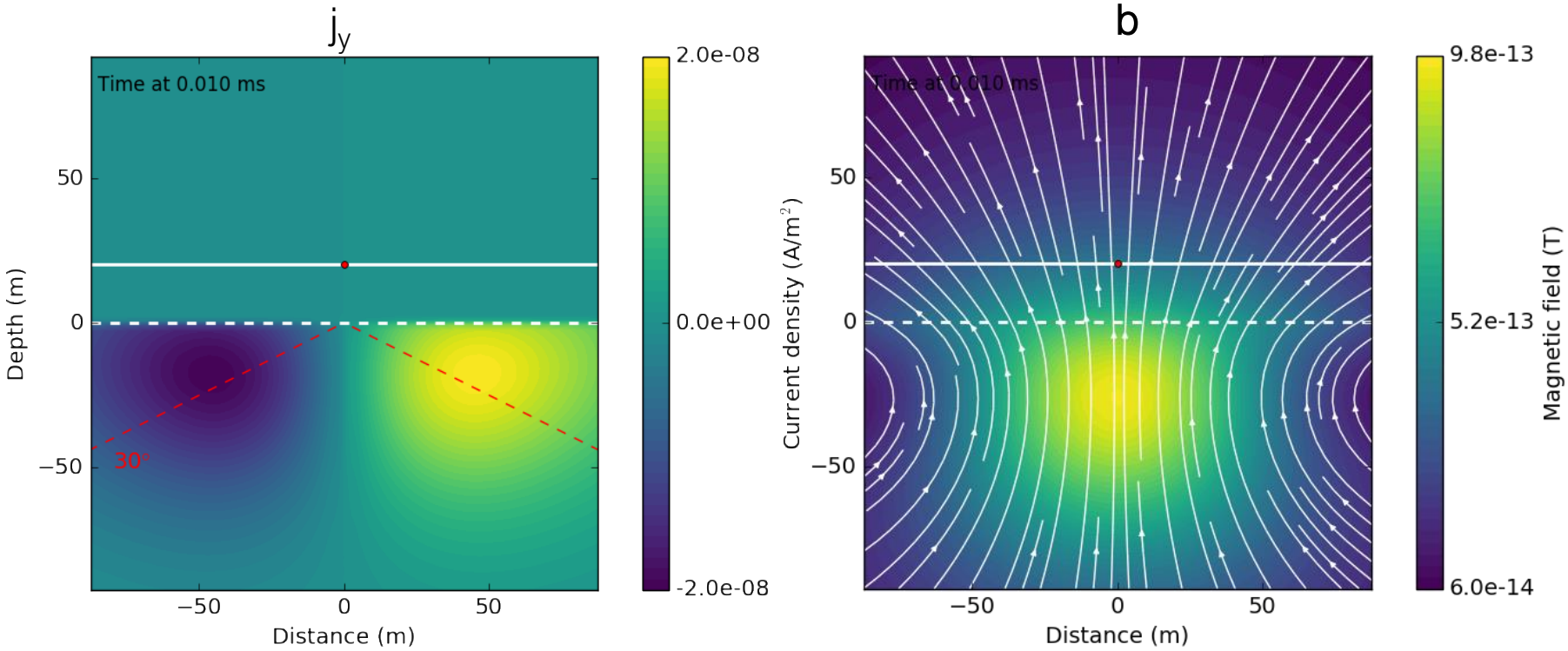


Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Propagation through time

- Time: 0.035ms
- diffusion distance = 75 m

$$d = 1260\sqrt{t\rho}$$

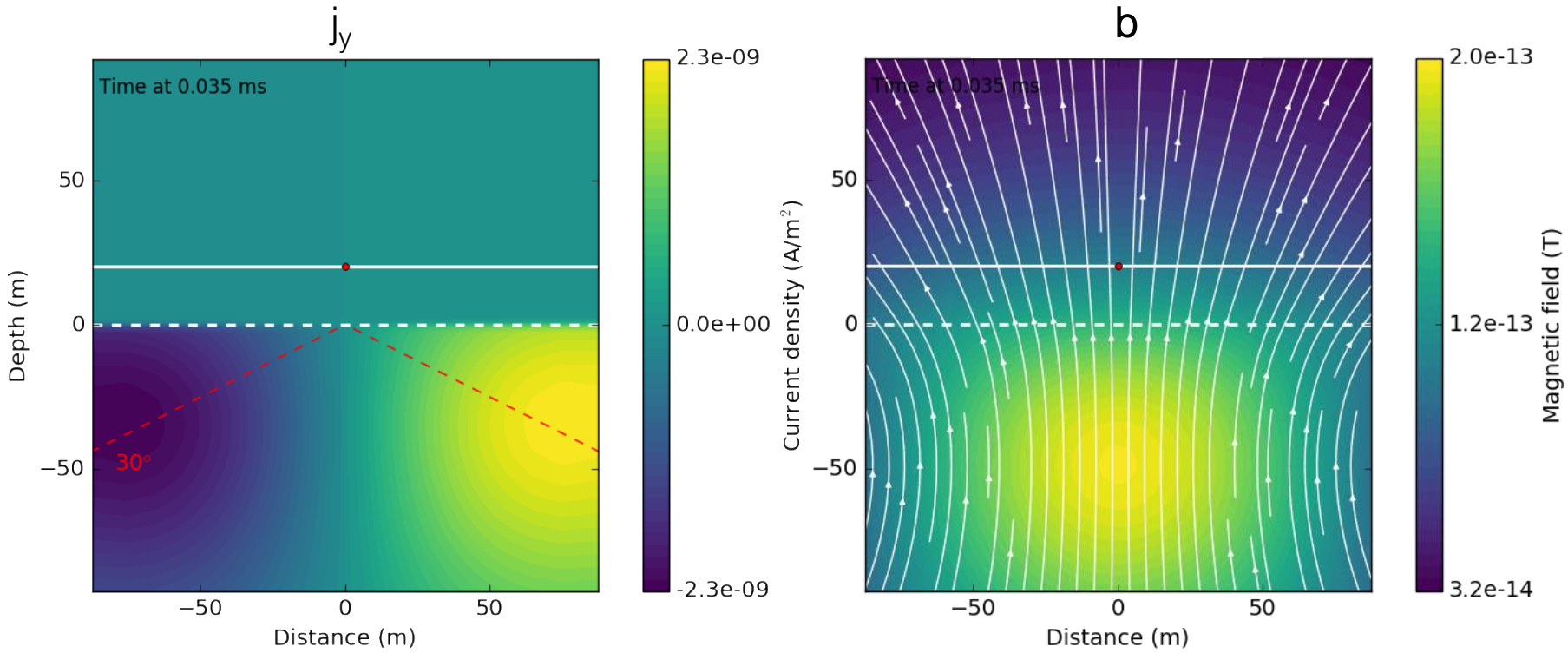


Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Propagation through time

- Time: 0.110ms
- diffusion distance = 132 m

$$d = 1260\sqrt{t\rho}$$

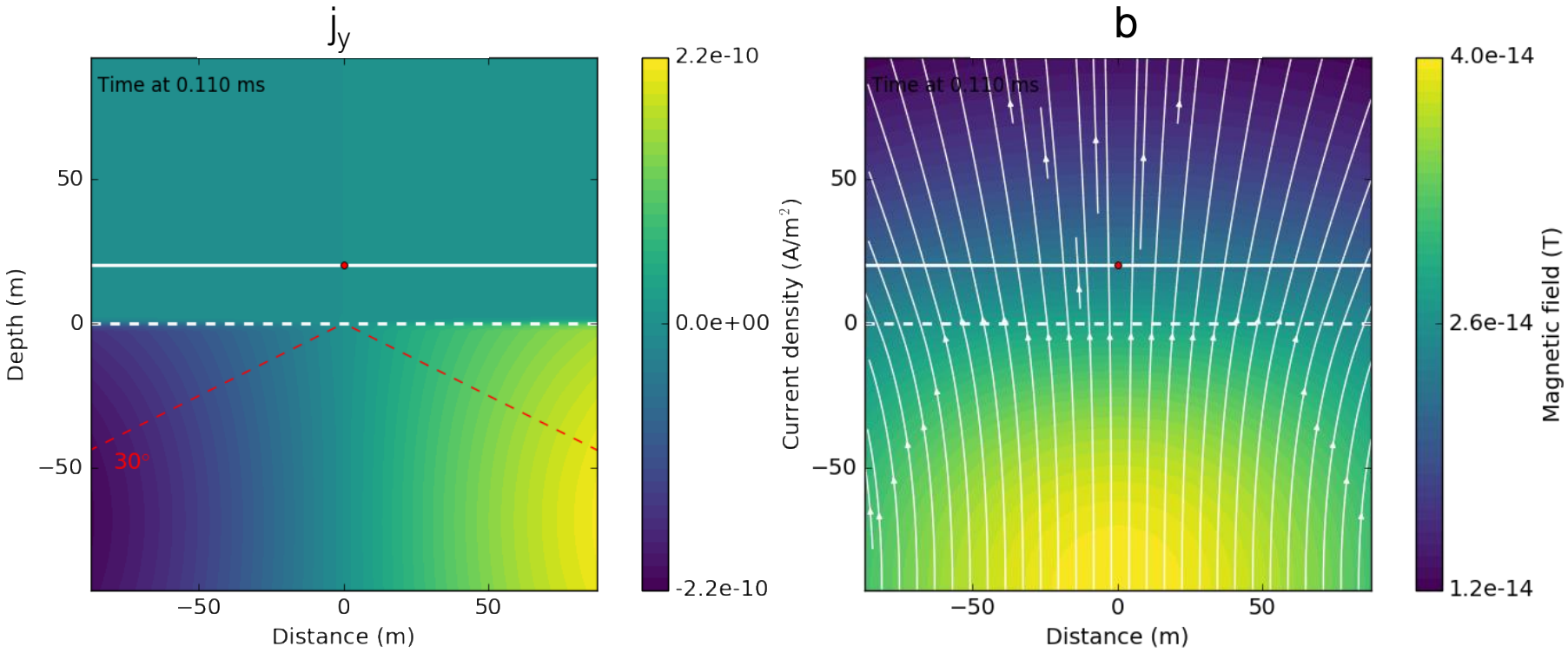
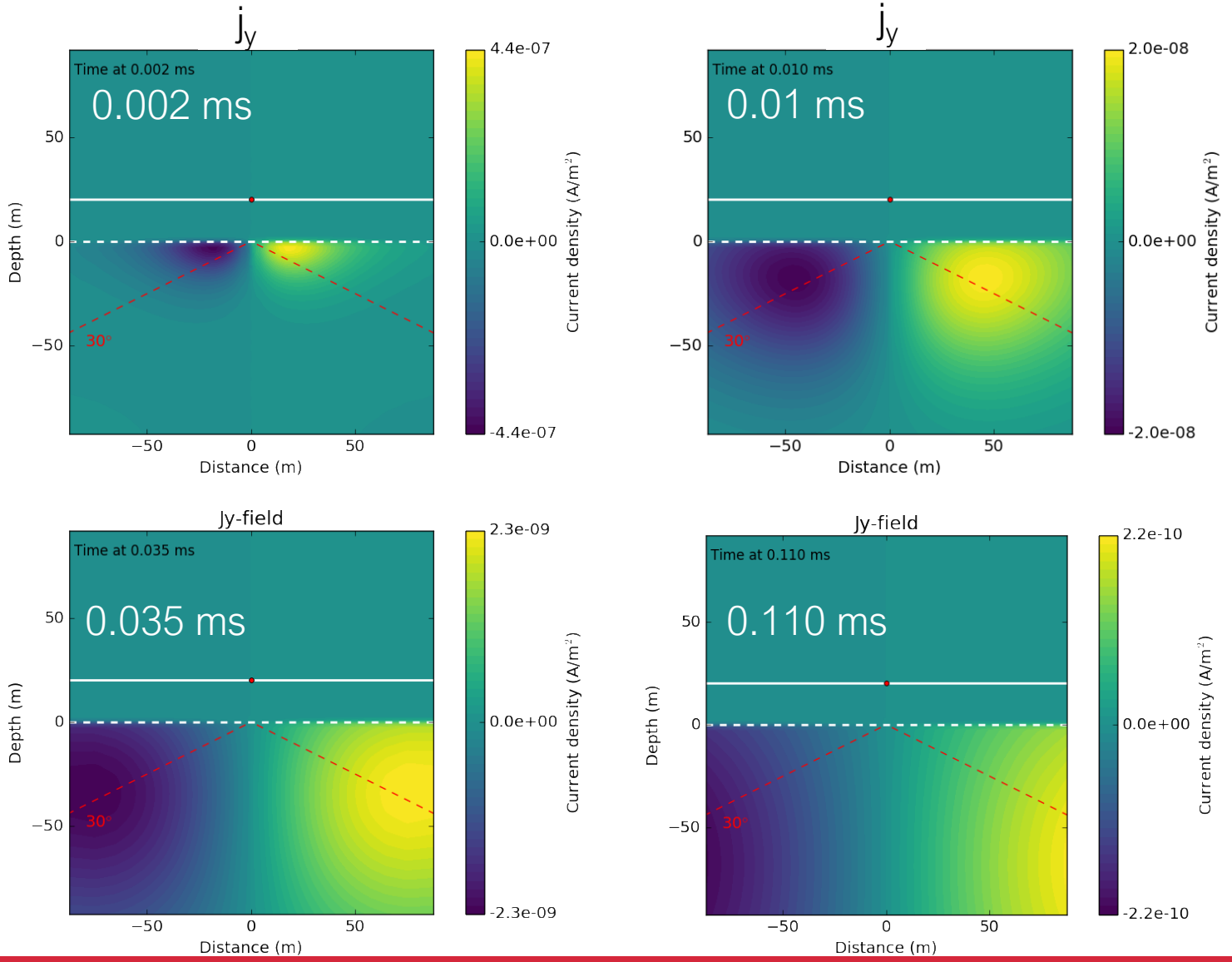


Image credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

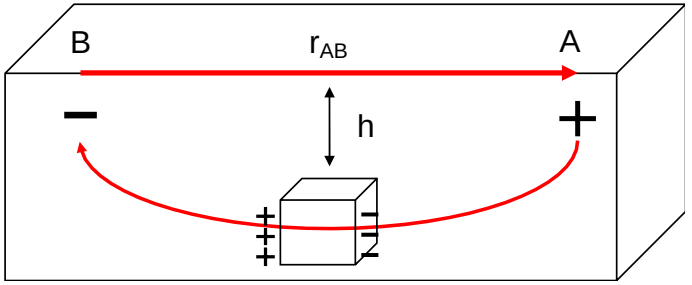
Summary: propagation through time



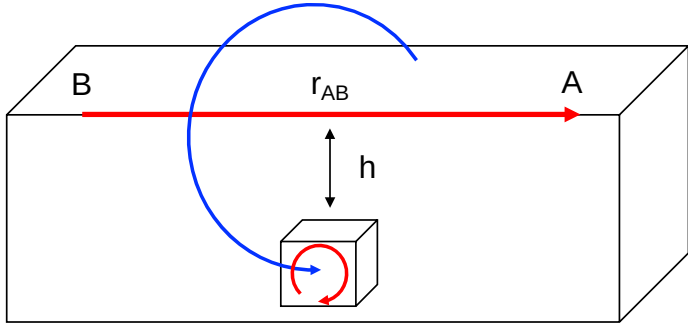
Grounded source EM: with a target

Grounded sources: with a target

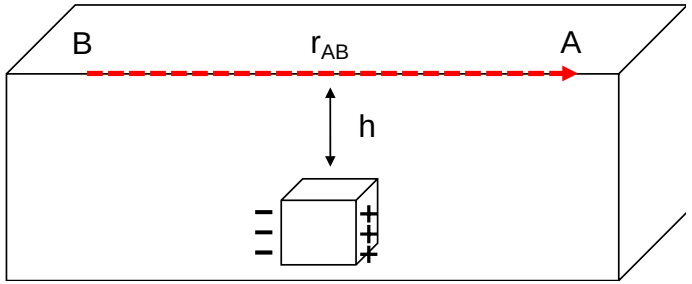
- Block in a halfspace
  - DC
    - Good coupling if h < r_{AB}



  - Vortex currents
    - Good coupling (magnetic fields)
    - Good signal for conductor
    - Resistor more difficult

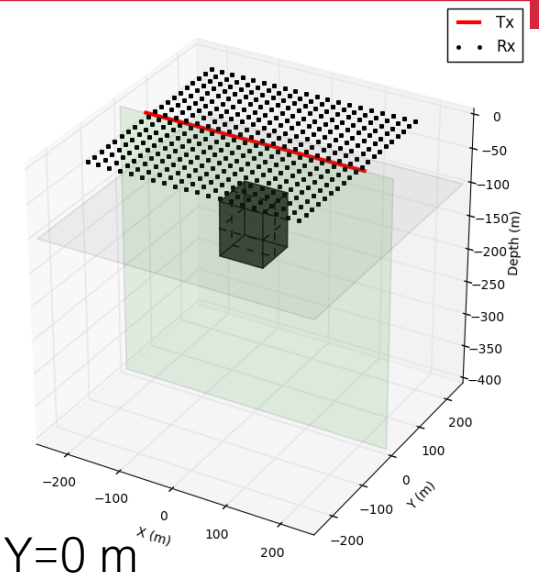


  - Galvanic currents
    - Good coupling (electric fields)
    - Good signal for conductor and resistor

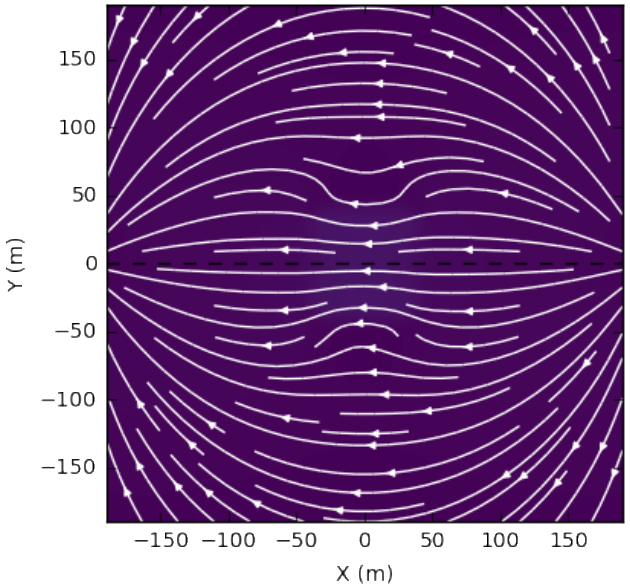


Conductor: currents

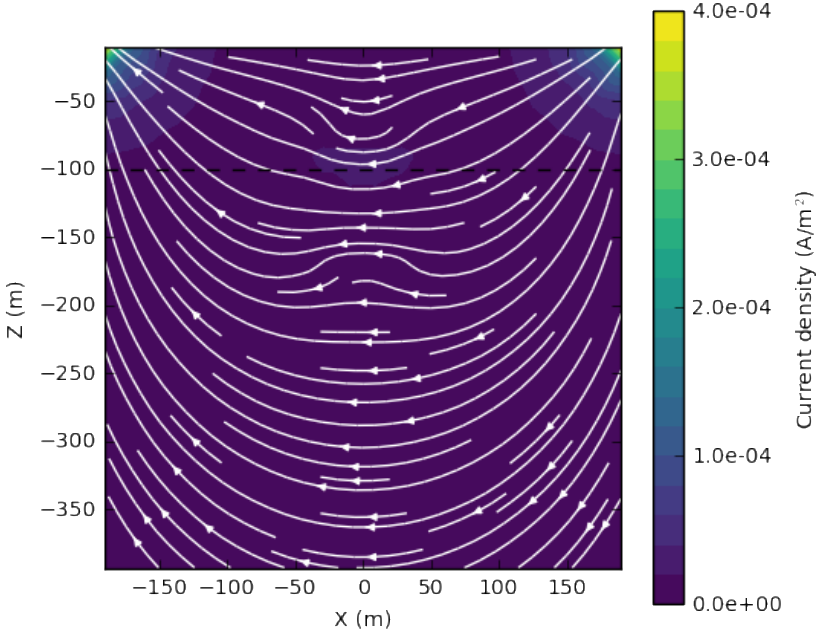
- Grounded wire
  - A conductor (1S/m) in a halfspace (0.01 S/m)
  - $t=0^-$, steady state



XY plane at Z=-100 m



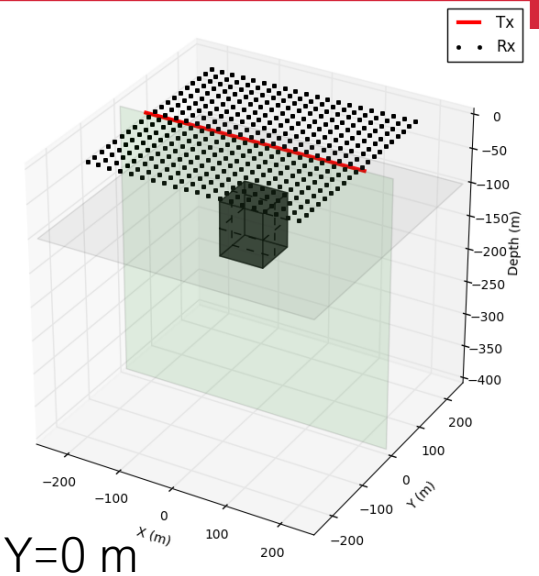
XZ plane at Y=0 m



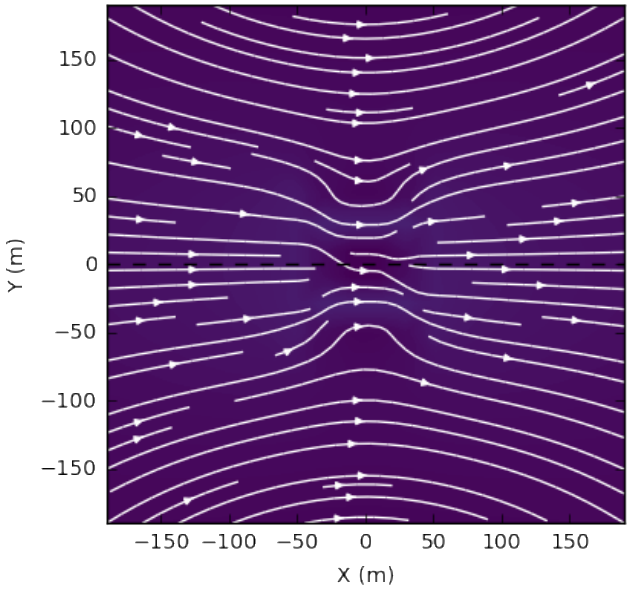
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Conductor: currents

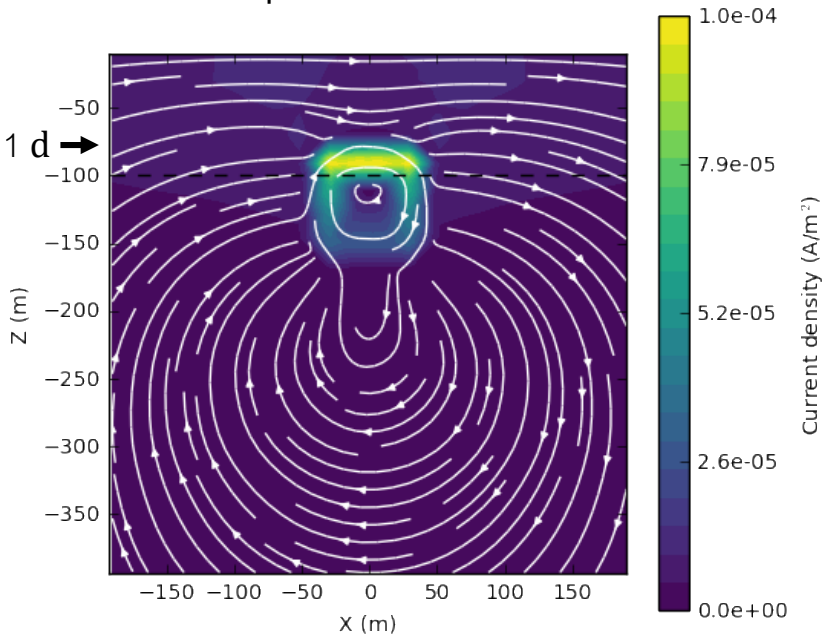
- Grounded wire
  - A conductor (1S/m) in a halfspace (0.01 S/m)
  - **0.04** ms, d = 80 m



XY plane at Z=-100 m



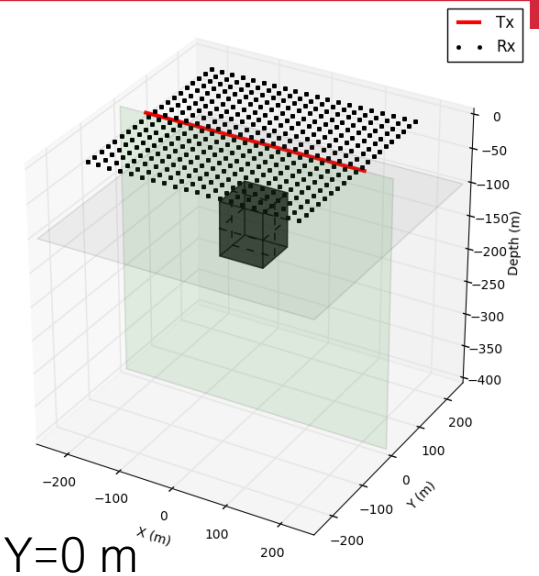
XZ plane at Y=0 m



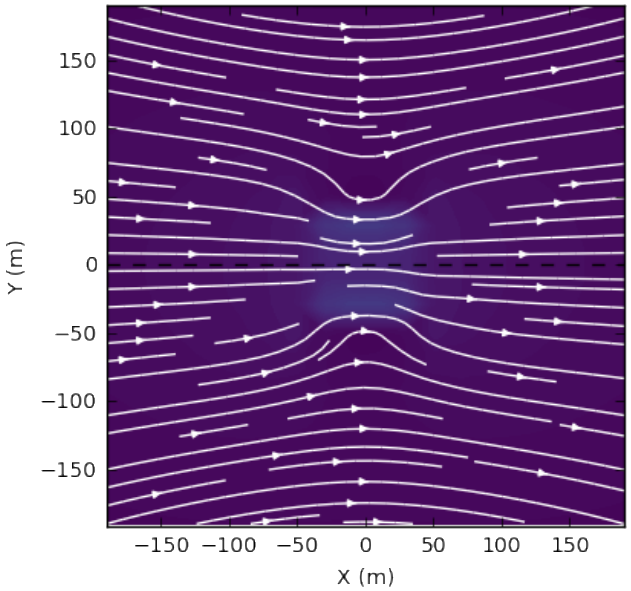
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Conductor: currents

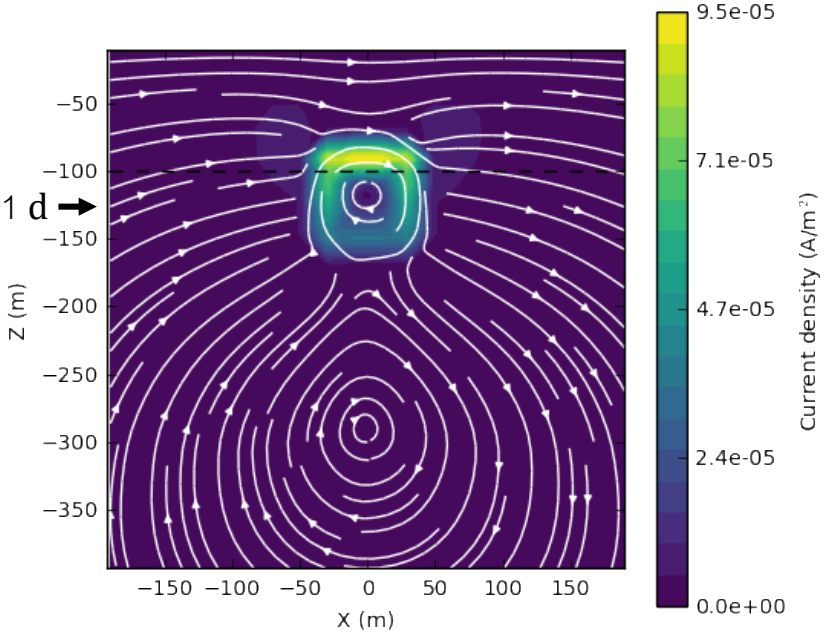
- Grounded wire
  - A conductor (1S/m) in a halfspace (0.01 S/m)
  - **0.1** ms, d = 126 m



XY plane at Z=-100 m



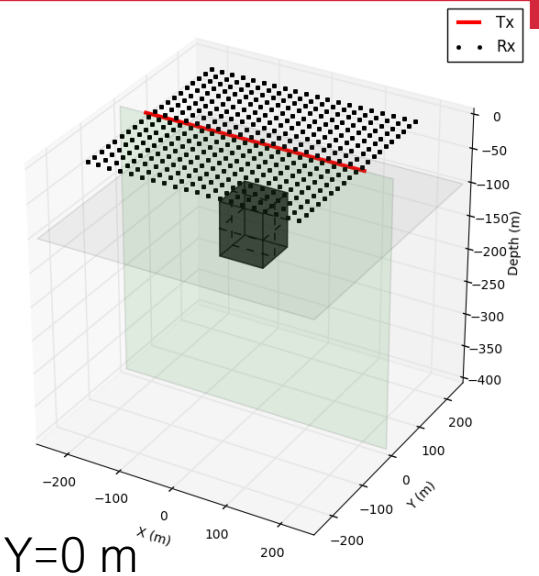
XZ plane at Y=0 m



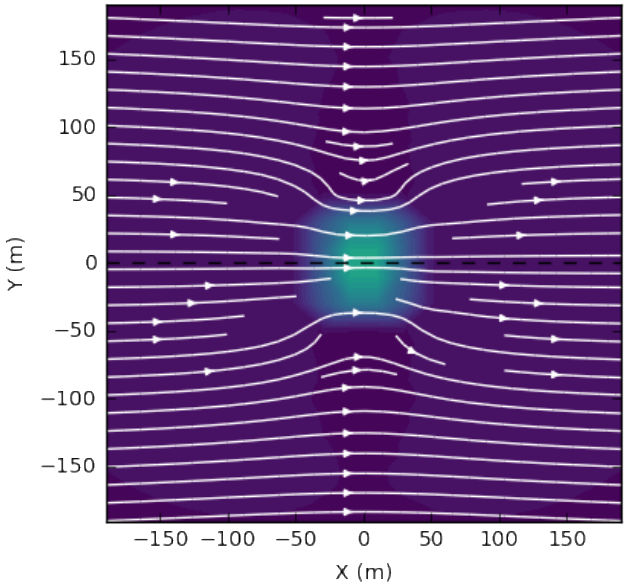
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Conductor: currents

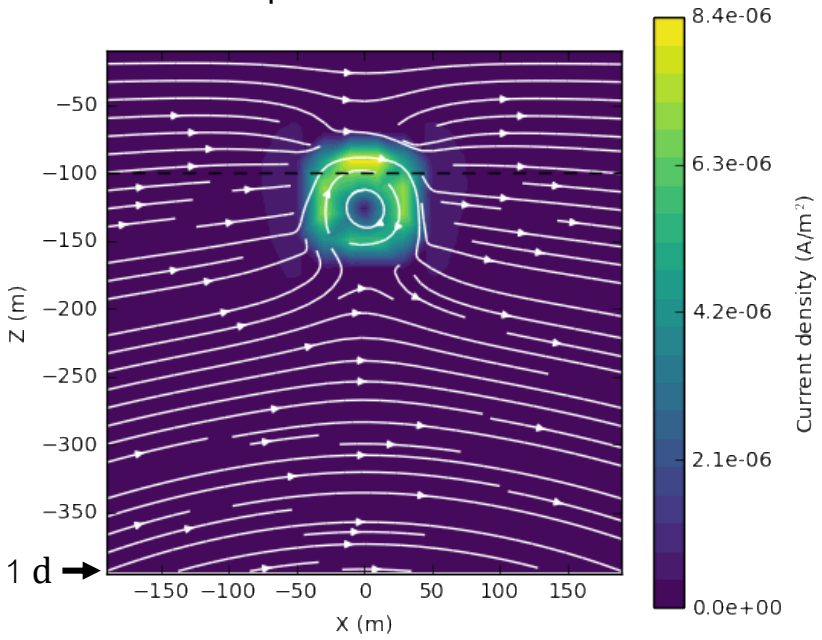
- Grounded wire
  - A conductor (1S/m) in a halfspace (0.01 S/m)
  - 1 ms, d = 400 m



XY plane at Z=-100 m



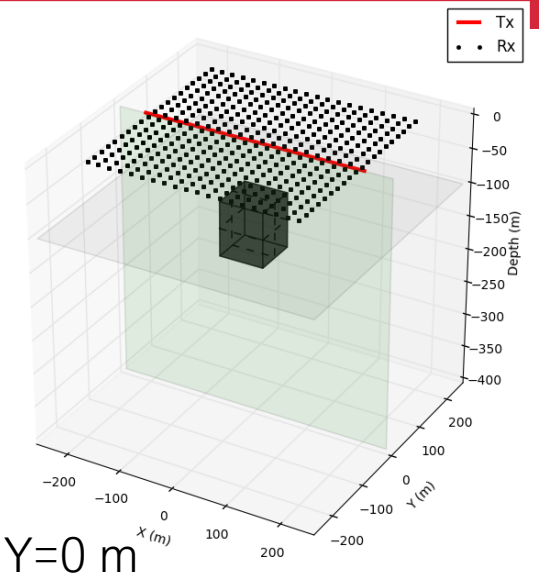
XZ plane at Y=0 m



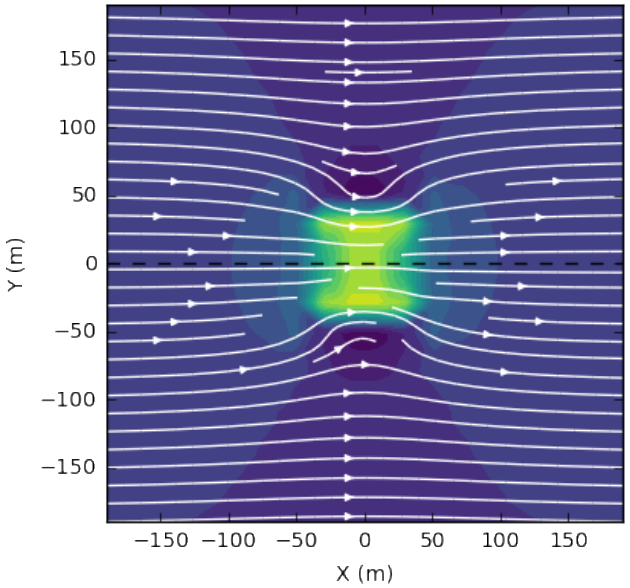
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Conductor: currents

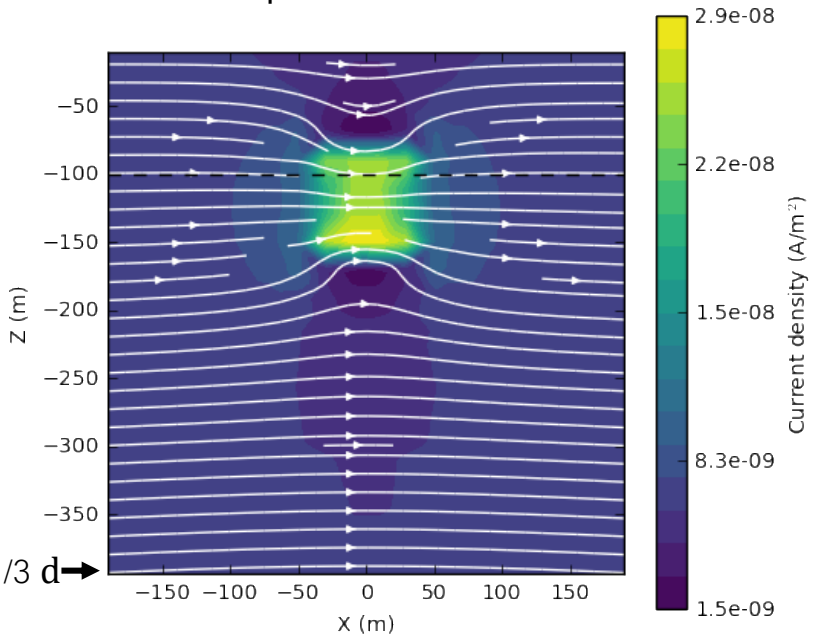
- Grounded wire
  - A conductor (1S/m) in a halfspace (0.01 S/m)
  - **10** ms, d = 1270 m



XY plane at Z=-100 m

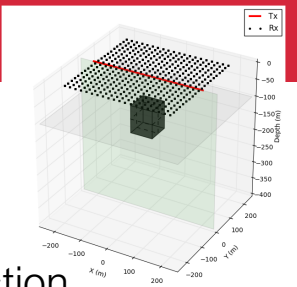


XZ plane at Y=0 m



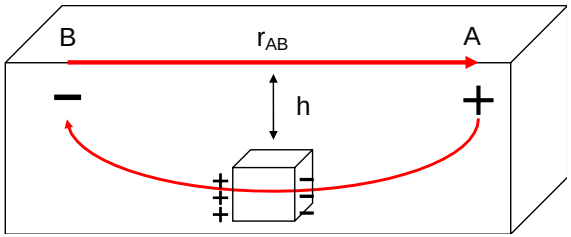
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Conductor: currents

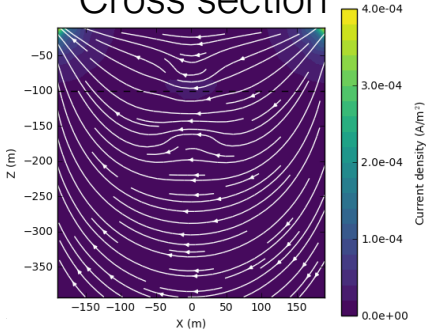


Cross section

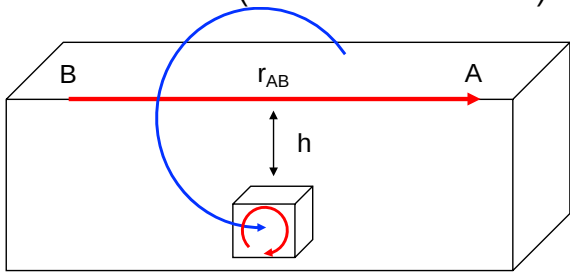
Steady State (galvanic current)



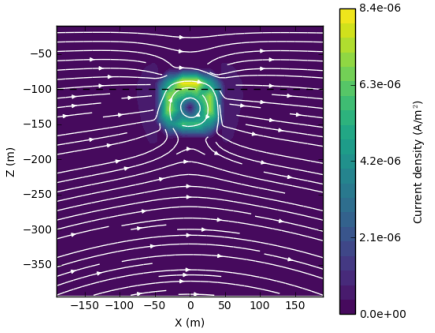
Galvanic current
$t = 0^-$



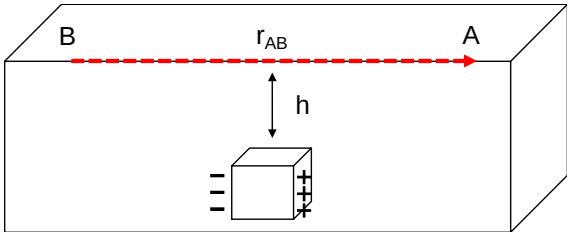
EM induction (vortex current)



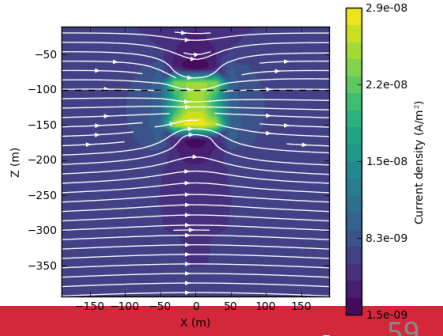
Vortex current
$t = 1$ ms



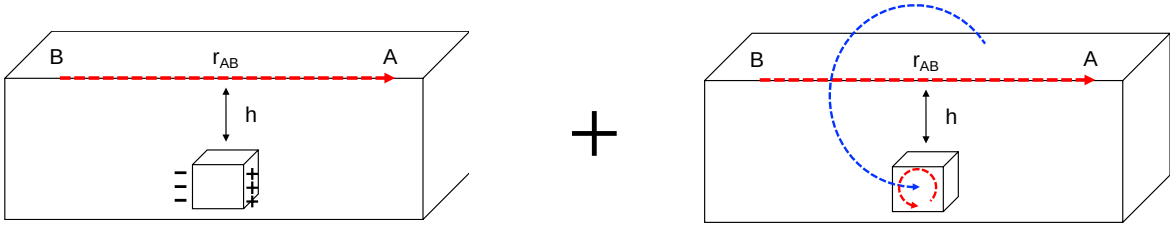
EM induction (galvanic current)

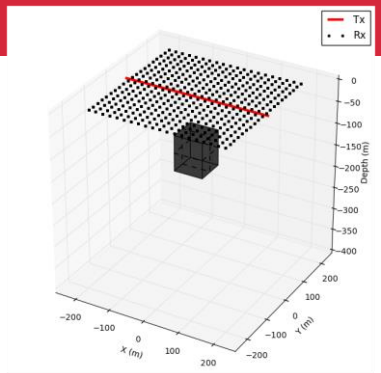


Galvanic current
$t = 10$ ms

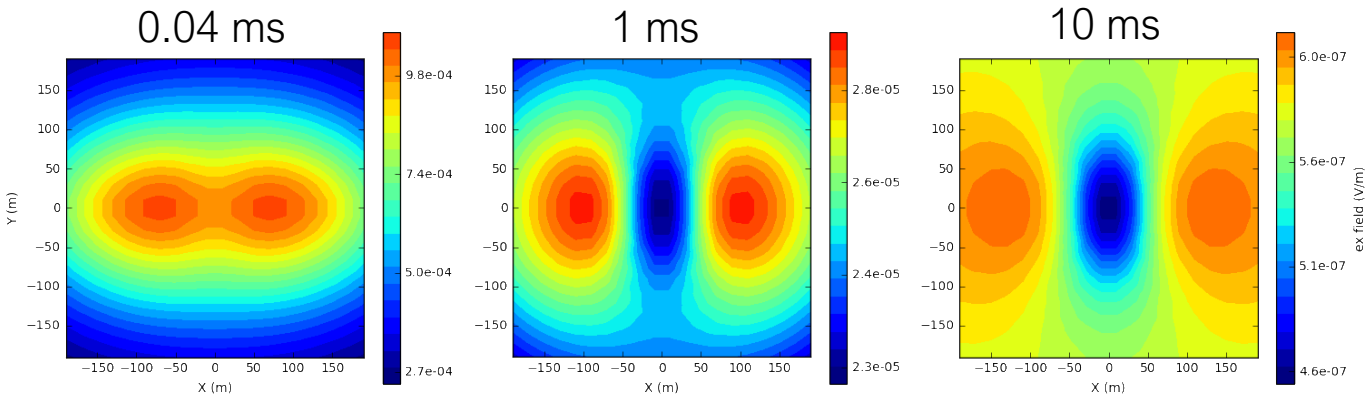


Data: e_x field

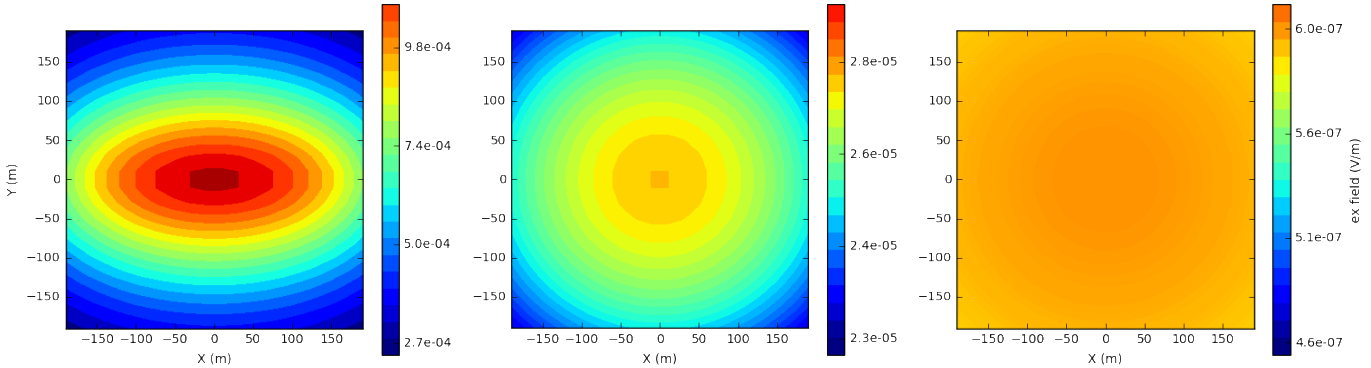




Conductor

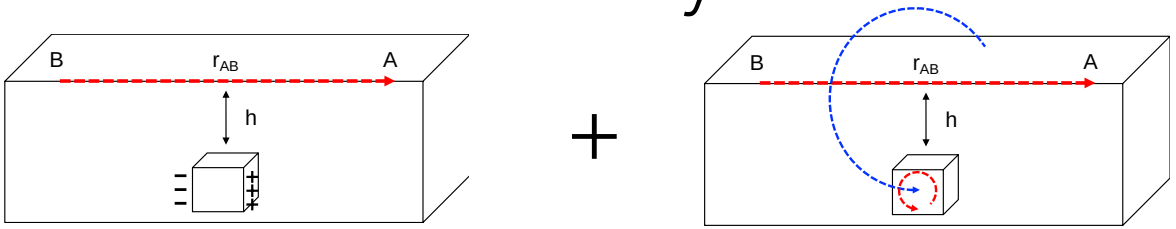


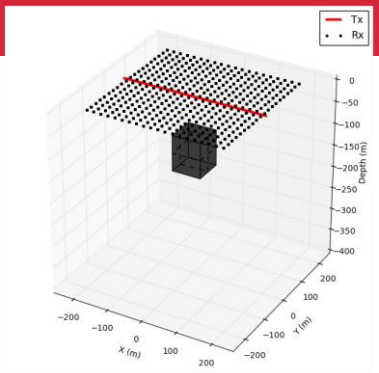
Halfspace



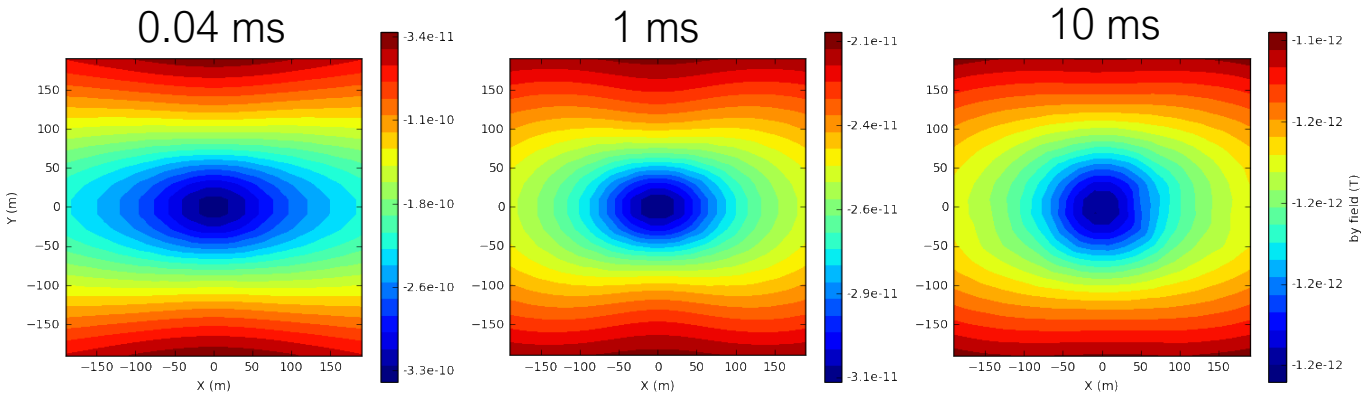
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Data: b_y field

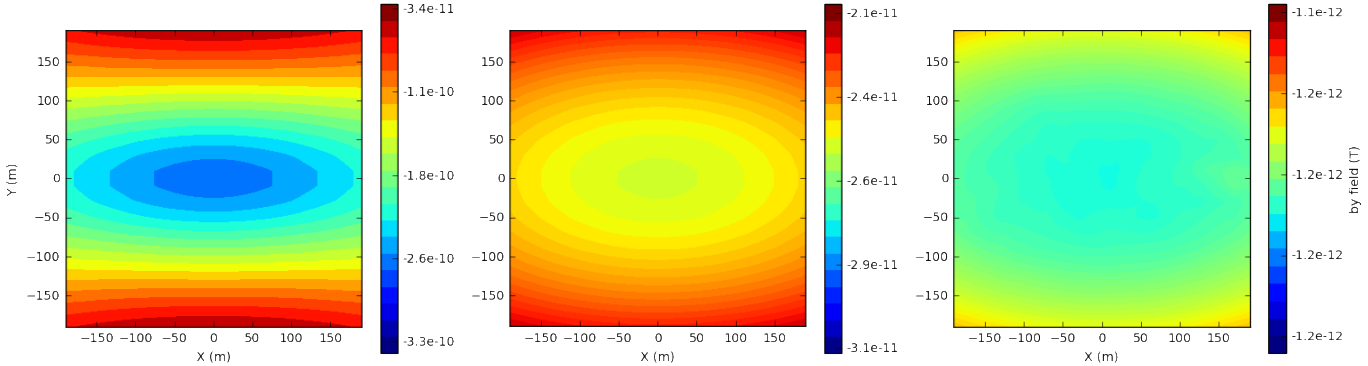




Conductor

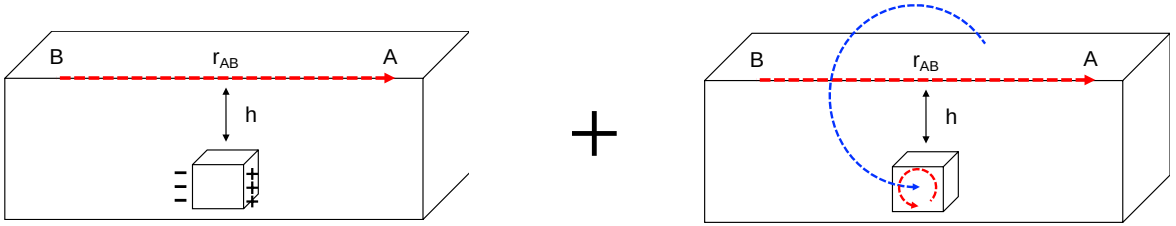


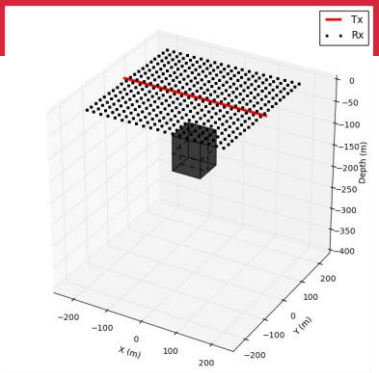
Halfspace



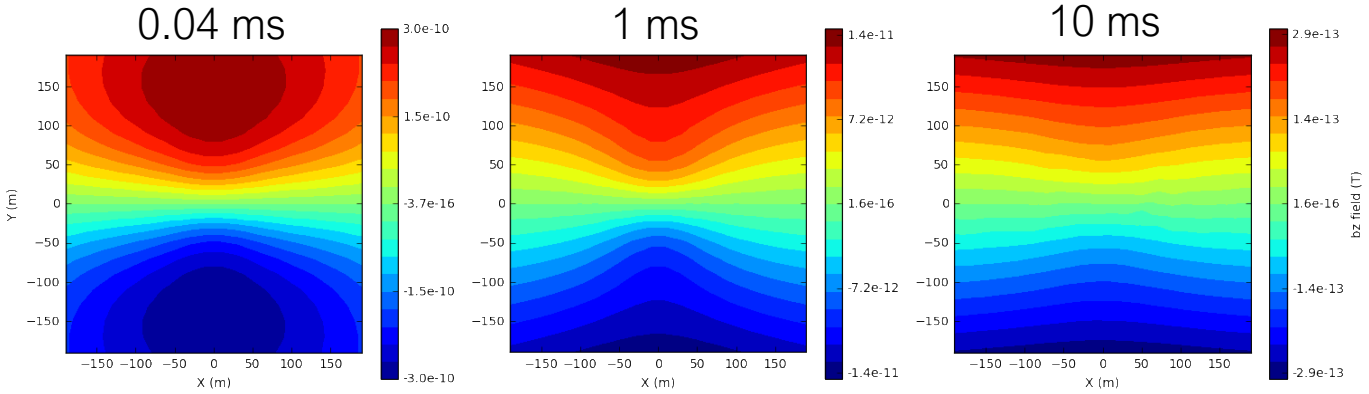
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Data: b_z field

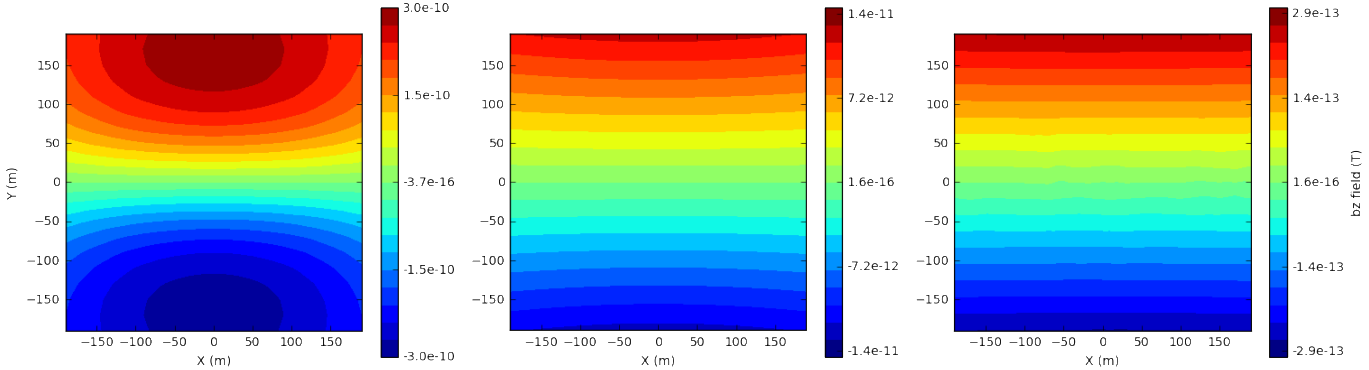




Conductor



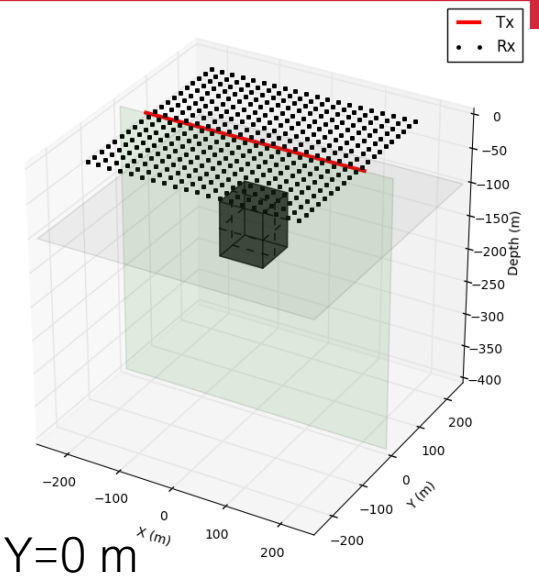
Halfspace



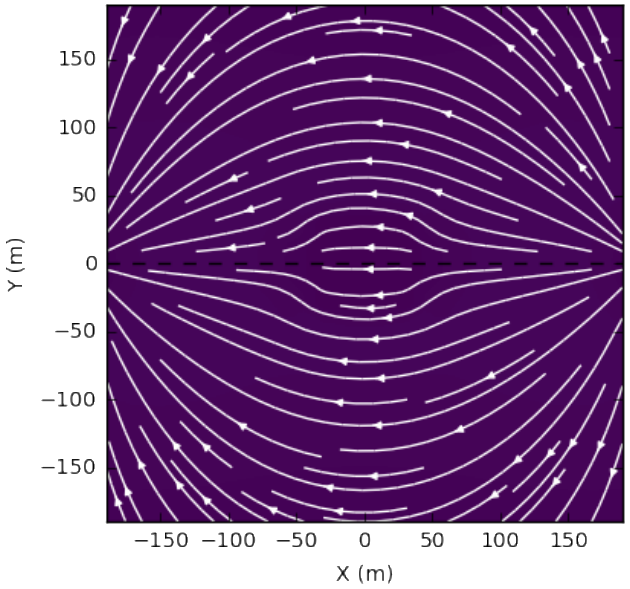
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Resistor: currents

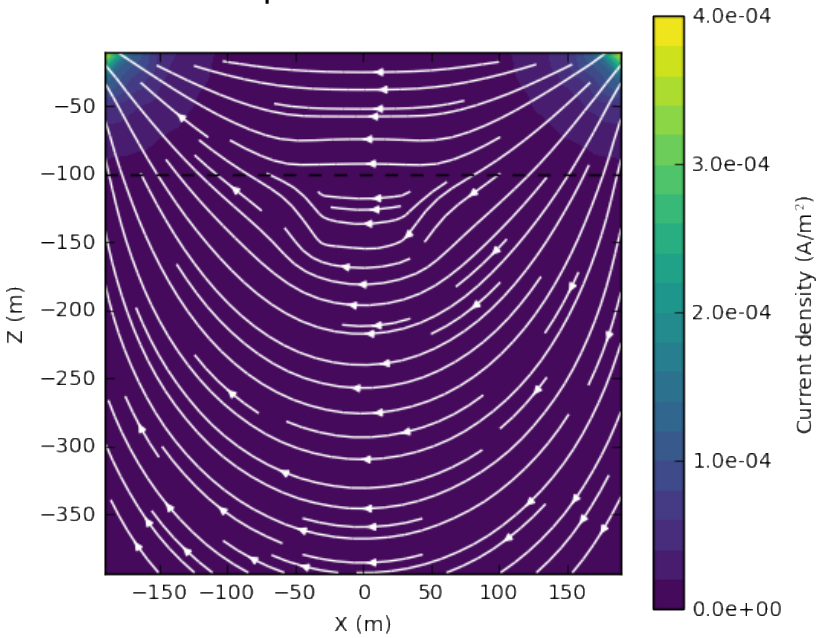
- Grounded wire
  - A resistor (10^{-4} S/m) in a halfspace (0.01 S/m)
  - $t=0^{-}$, steady state



XY plane at Z=-100 m

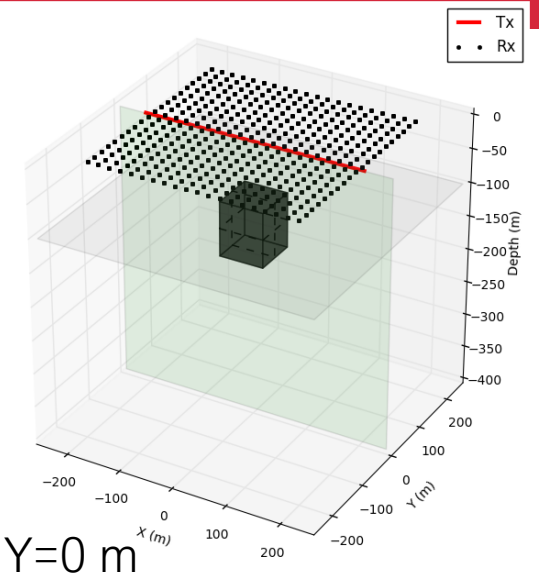


XZ plane at Y=0 m

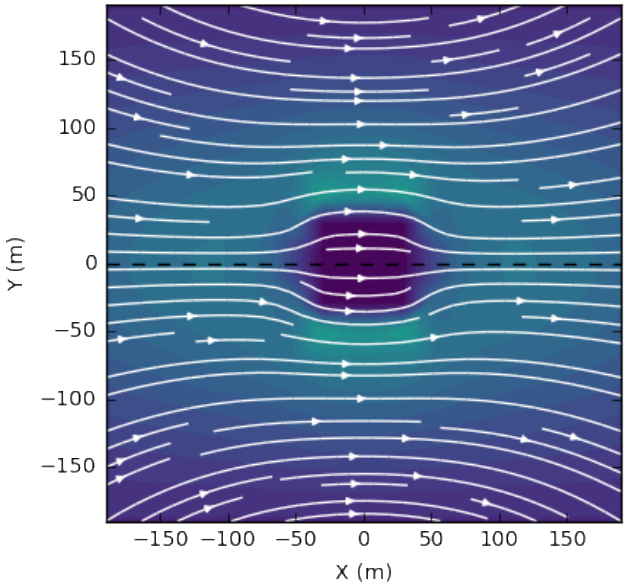


Resistor: currents

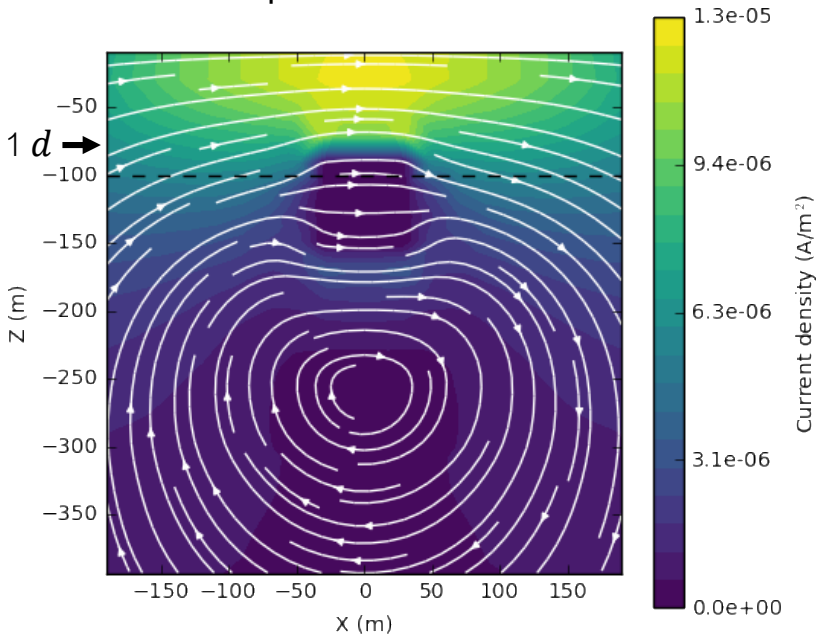
- Grounded wire
  - A resistor (10^{-4} S/m) in a halfspace (0.01 S/m)
  - **0.04** ms, d = 80 m



XY plane at Z=-100 m



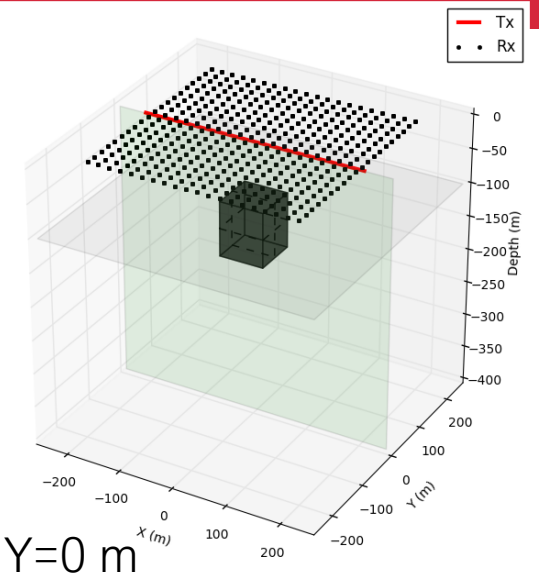
XZ plane at Y=0 m



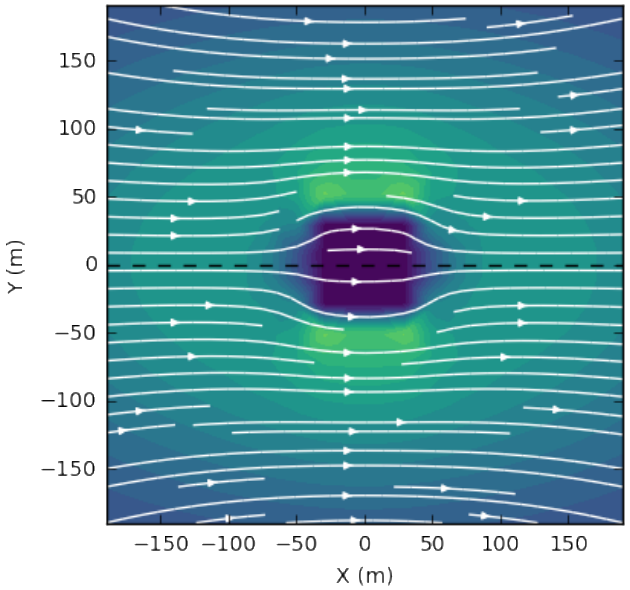
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Resistor: currents

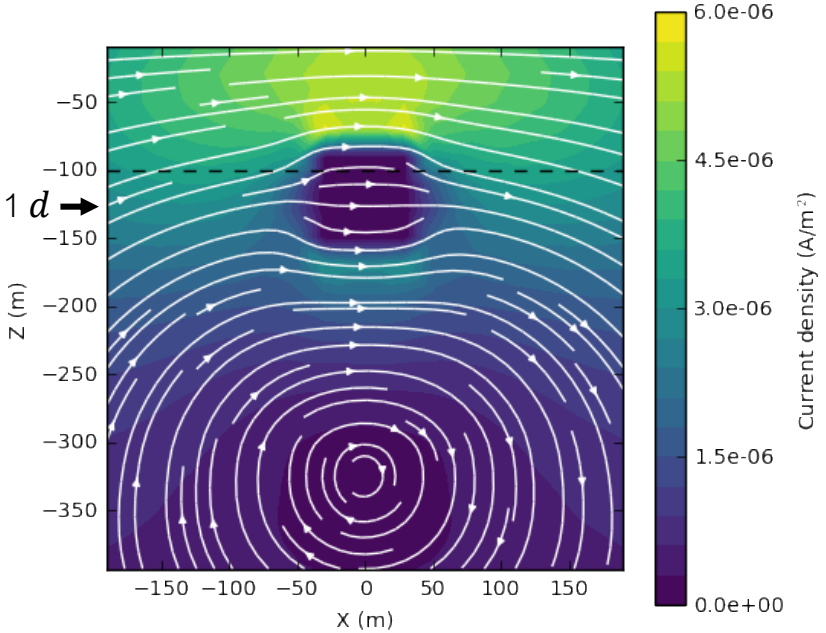
- Grounded wire
  - A resistor (10^{-4} S/m) in a halfspace (0.01 S/m)
  - **0.1** ms, d = 126 m



XY plane at Z=-100 m



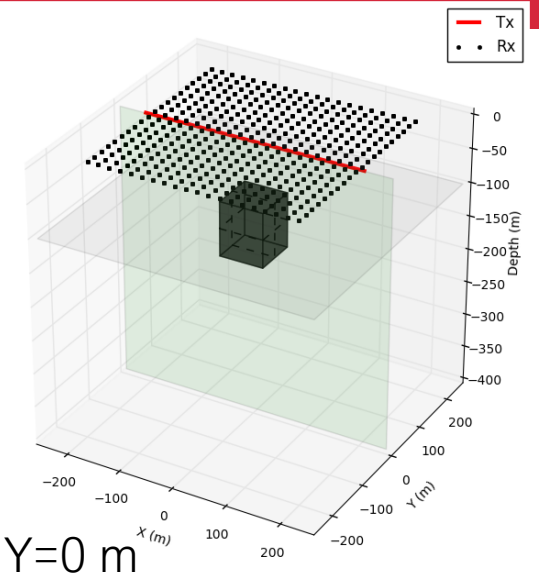
XZ plane at Y=0 m



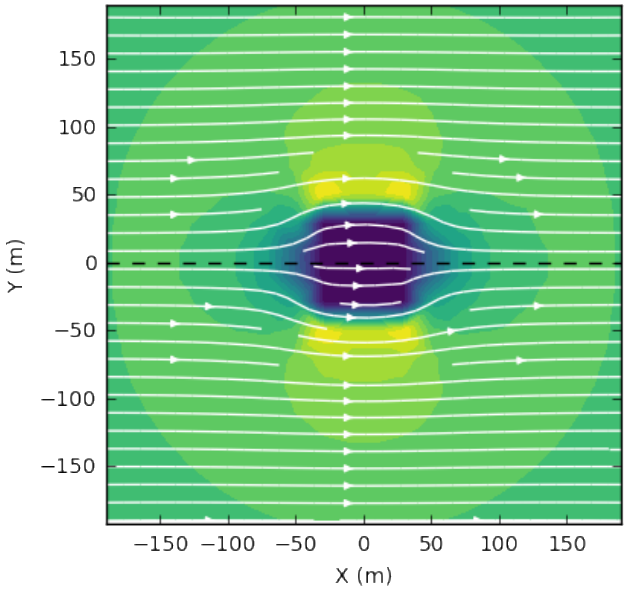
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Resistor: currents

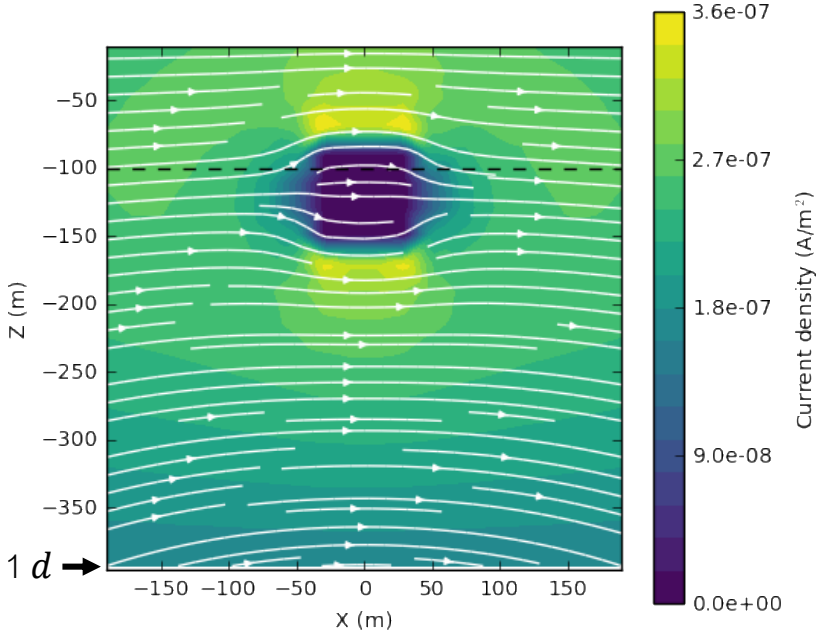
- Grounded wire
  - A resistor (10^{-4} S/m) in a halfspace (0.01 S/m)
  - 1 ms, d = 400 m



XY plane at Z=-100 m



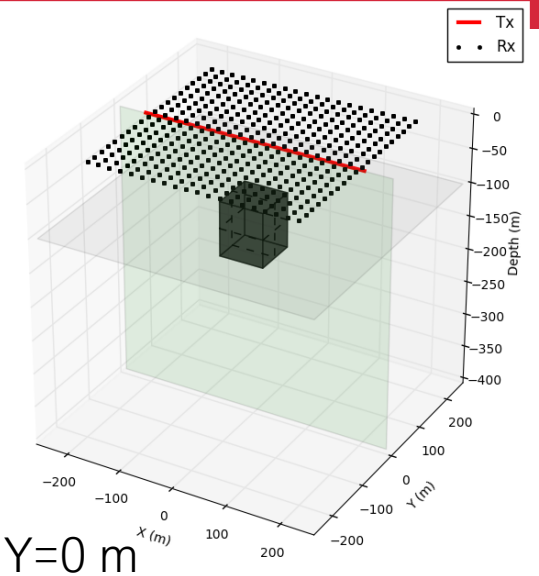
XZ plane at Y=0 m



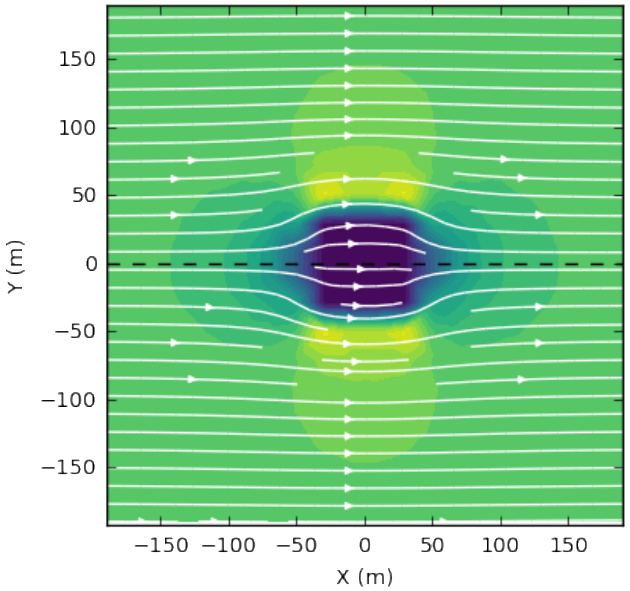
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Resistor: currents

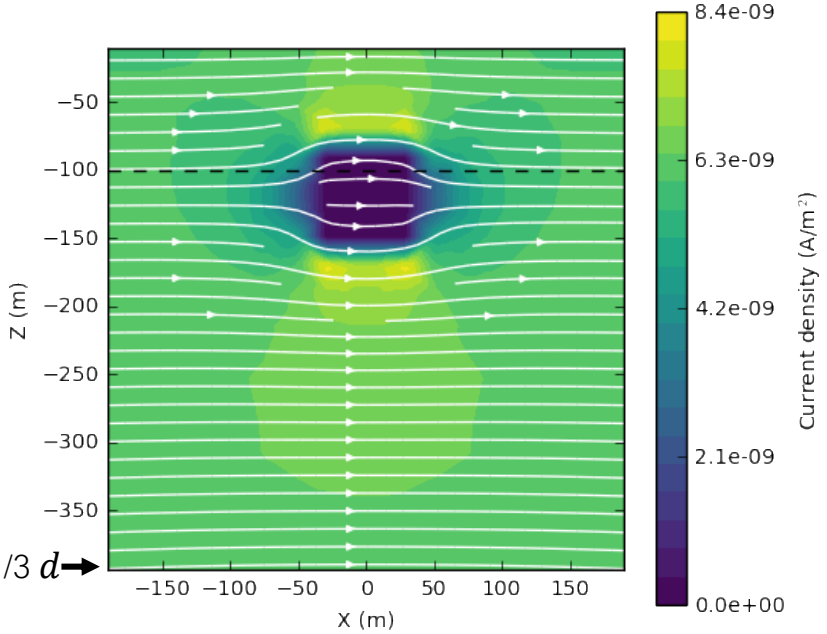
- Grounded wire
  - A resistor (10^{-4} S/m) in a halfspace (0.01 S/m)
  - **10** ms, d = 1270 m



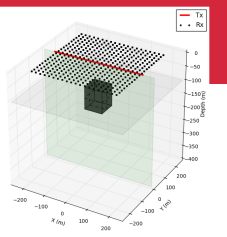
XY plane at Z=-100 m



XZ plane at Y=0 m

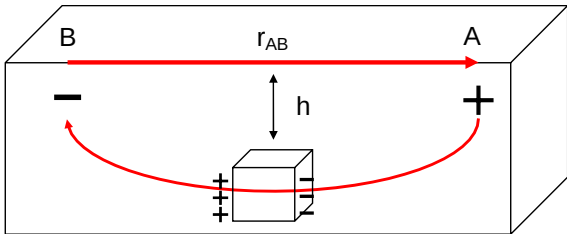


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF



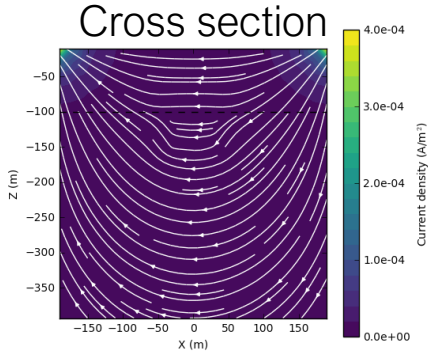
Resistor: currents

DC (galvanic current)

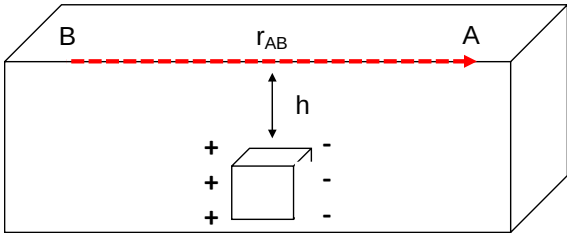


Galvanic current
t = 0-

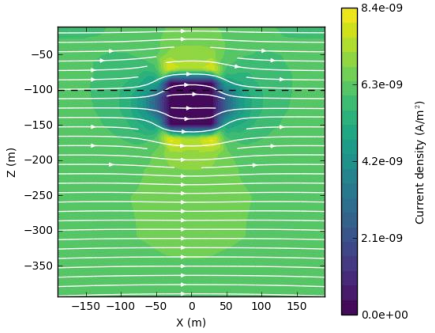
Cross section



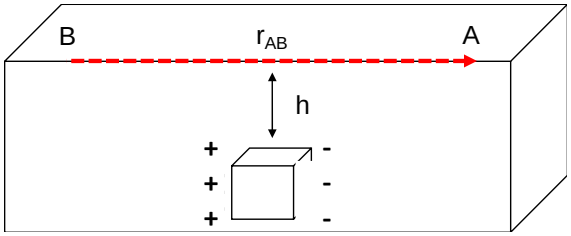
EM induction (galvanic current)



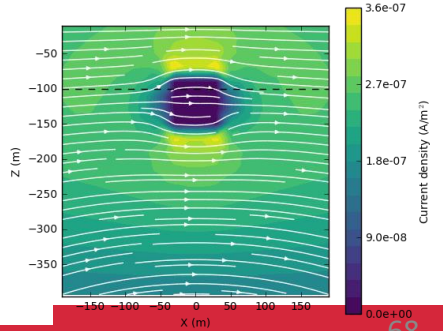
Galvanic current
t = 1 ms



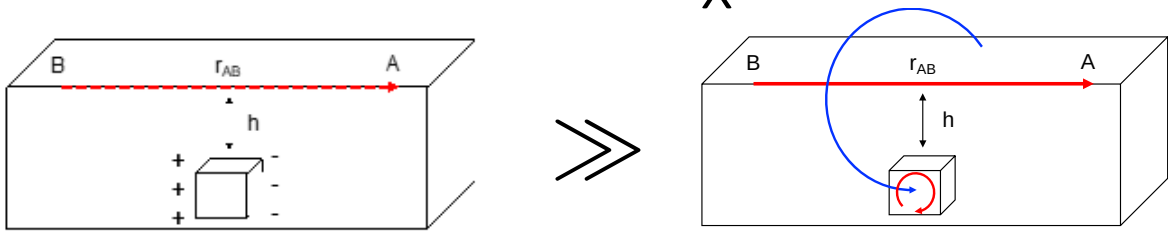
EM induction (galvanic current)



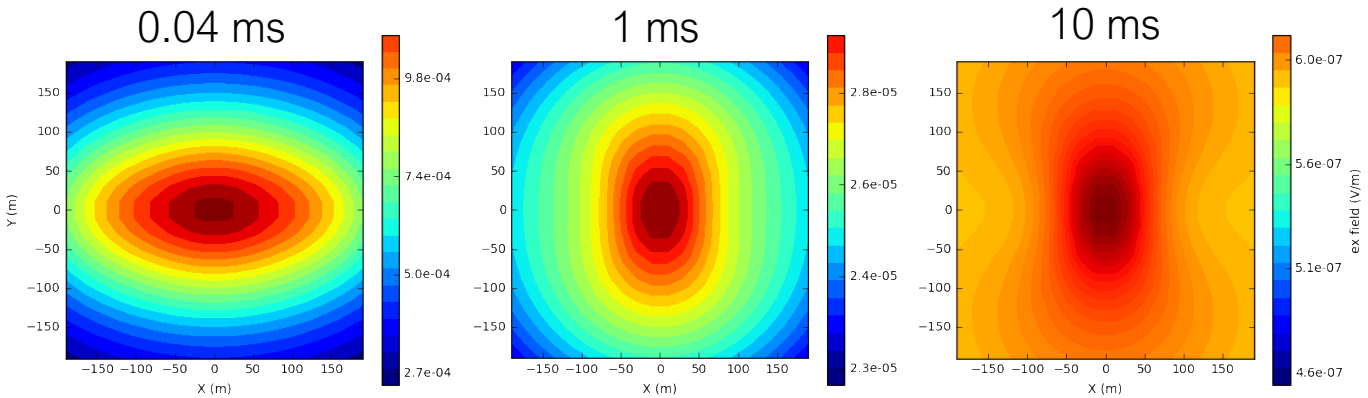
Galvanic current
t = 10 ms



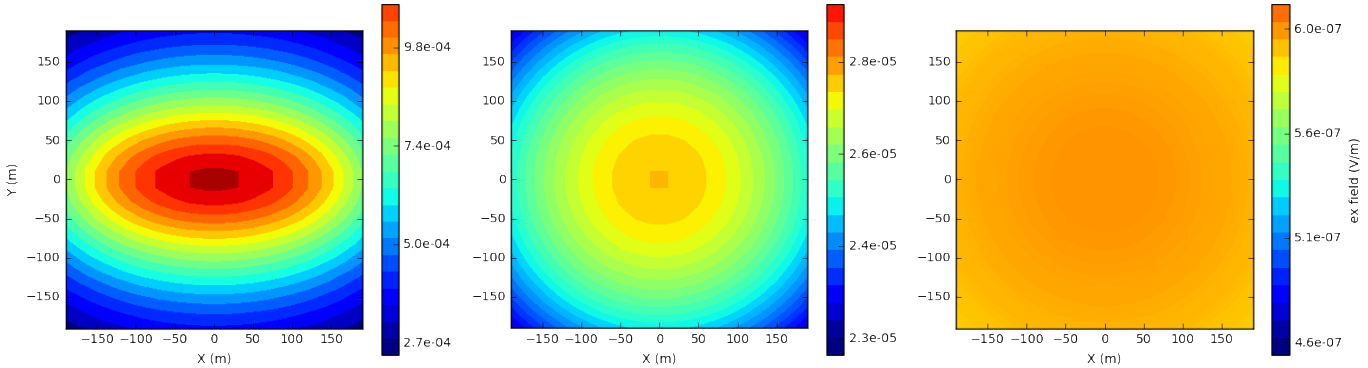
Data: e_x field



Resistor

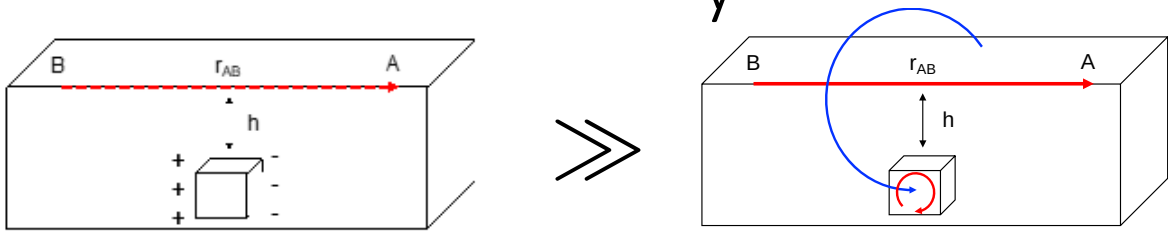


Halfspace

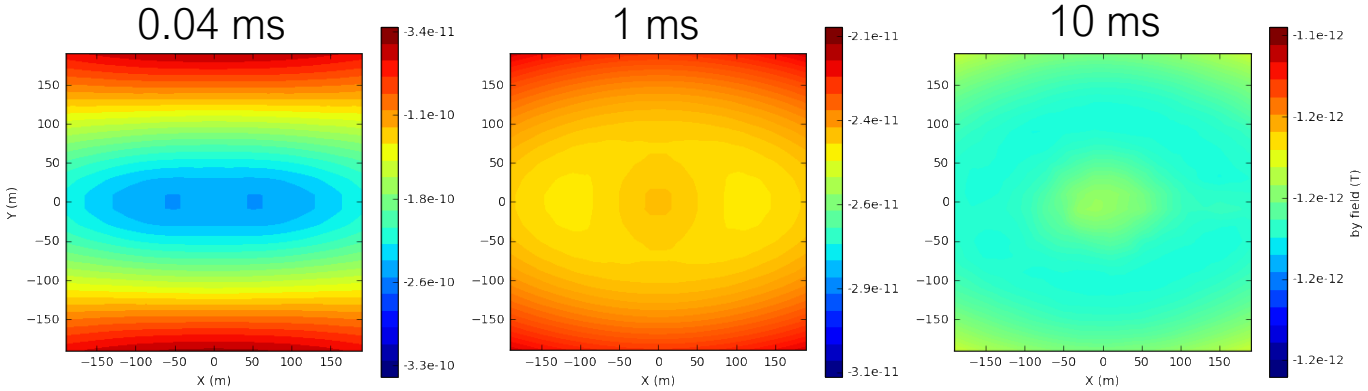


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

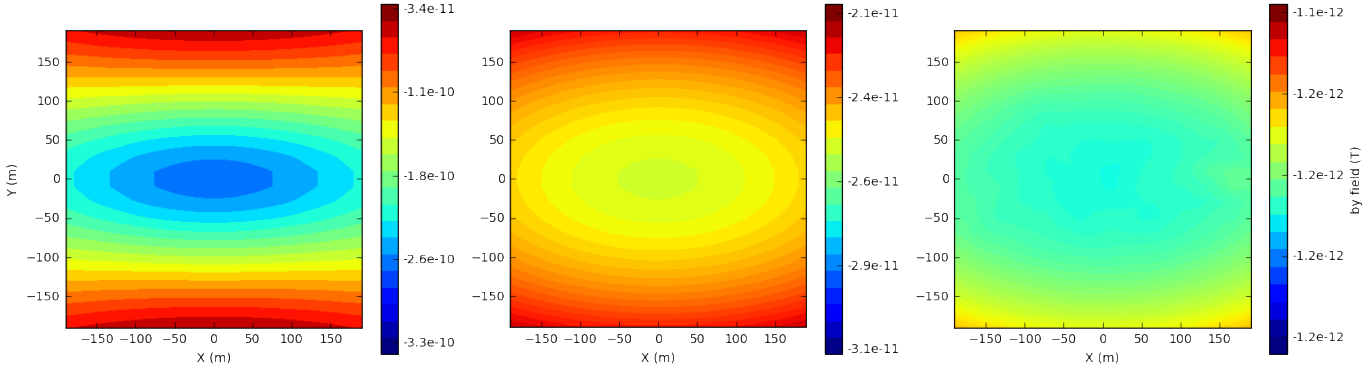
Data: b_y field



Resistor

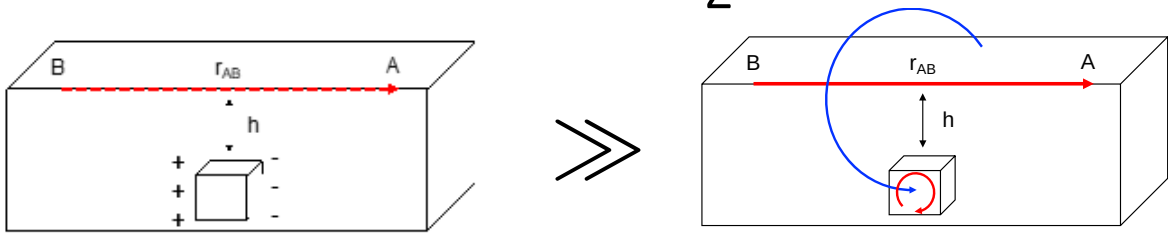


Halfspace

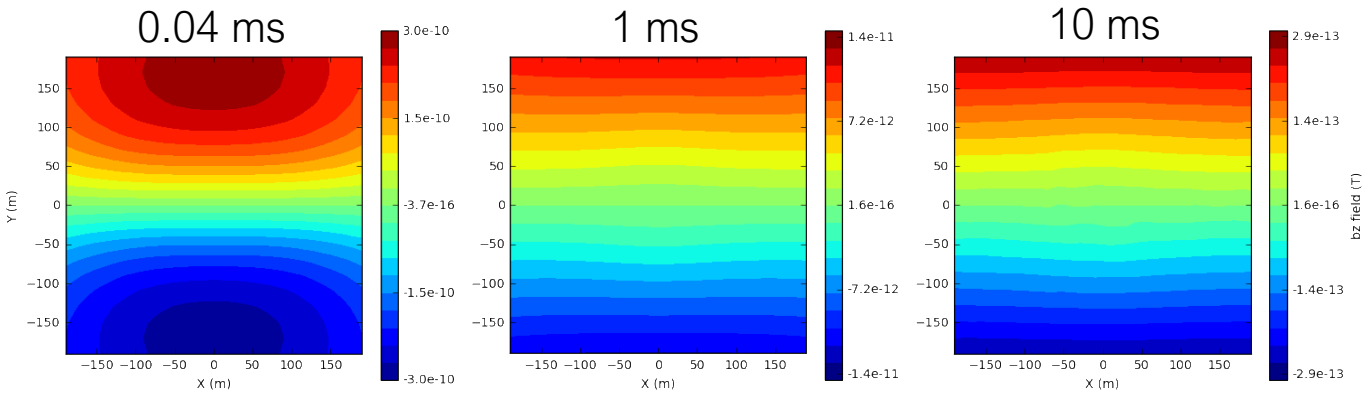


Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

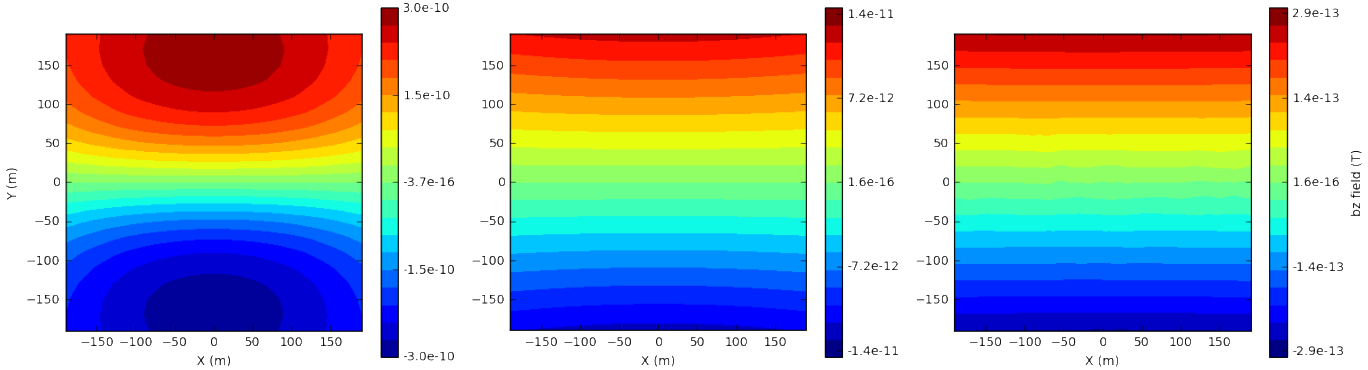
Data: b_z field



Resistor



Halfspace



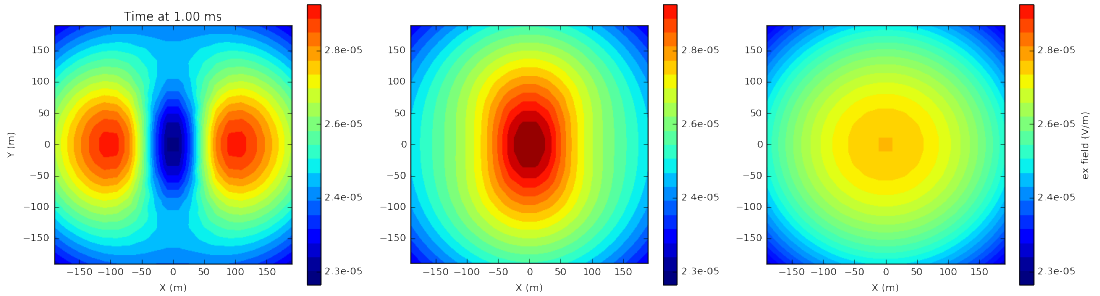
Credit: Doug Oldenburg, Seogi Kang and Linsey Heagy from UBC-GIF

Data summary

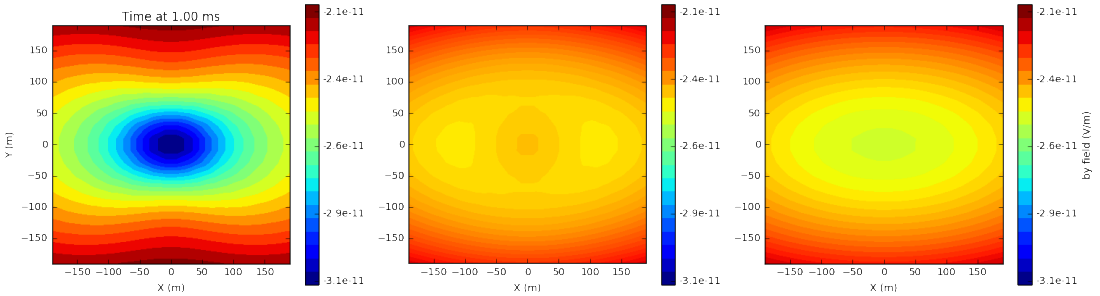
t = 1ms

Conductor Resistor Halfspace

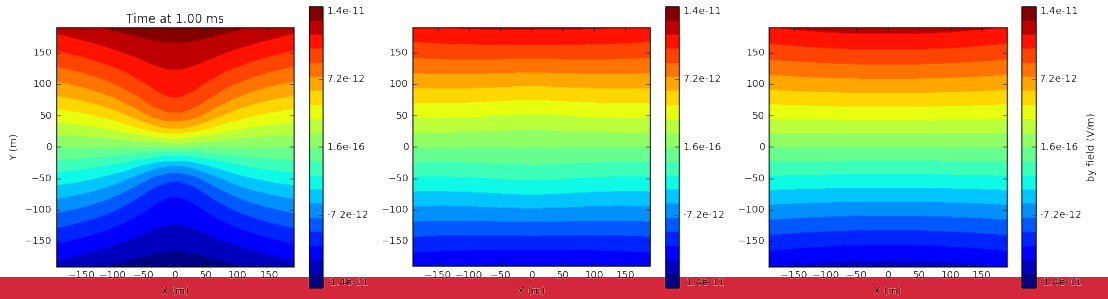
e_x



b_y



b_z



Summary

- Ex, By are more sensitive to conductor than resistor.
- Ex is more sensitive to resistor (than By and Bz).

- To look for a resistive target, E-field measurements are more useful.

- Finding resistors is more challenging than conductors, but with grounded sources, we now can find resistors!!